Vol. 2. No. 2. June, 1945.

THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

IMP. INST. ENT.
— LIBRARY —
27 DEC 1945
SERIAL
SEPARATE
Aus. 40

CONTENTS

PAGE.

Some Fundamental Relations between Soil Structure and Treatment. By N. G. CASSIDY 89

Studies on the Effects of Transport and Storage on the Bacteriological Quality of Raw Milk. Part 1. The Reduction of Methylene Blue by Raw Milk as Influenced by Time and Temperature of Storage. By V. R. SMYTHE 128

PUBLISHED QUARTERLY

By the Queensland Department of Agriculture and Stock, Brisbane

Issued by Direction of Hon. T. L. WILLIAMS,
Secretary for Agriculture and Stock.

EDITORIAL BOARD.

Editor: C. W. WINDERS, B.Sc.Agr.

A. F. BELL, M.Sc., D.I.C., A.A.C.I., Assistant Under Secretary (Technical), and Director, Bureau of Sugar Experiment Stations;

J. LEGG, B.Sc., D.V.Sc., M.R.C.V.S., Acting Director, Division of Animal Industry;

C. J. McKEON, Q.D.A., Director of Agriculture, Agriculture Branch, Division of Plant Industry;

J. F. F. REID, Editor of Departmental Publications;

J. H. SMITH, M.Sc., N.D.A., Officer in Charge, Science Branch, Division of Plant Industry;

W. A. T. SUMMERVILLE, D.Sc., Director of Horticulture, Horticulture Branch, Division of Plant Industry;

R. VEITCH, B.Sc.Agr., B.Sc.For., F.R.E.S., Director, Division of Plant Industry;

M. WHITE, M.Sc., Ph.D., A.A.C.I., Agricultural Chemist and Bio-chemist, Chemical Laboratory, Division of Plant Industry.

The Journal is supplied free, on request, to scientific agricultural and veterinary institutions and organizations. The price to other bodies and to individuals is ten shillings per volume or two shillings and sixpence per number. Subscriptions should be sent to the Under Secretary, Department of Agriculture and Stock, Brisbane, Queensland.

Copies lost in the post will be replaced if application is made within a reasonable time.

THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

VOL. 2. NO. 2.

JUNE, 1945

SOME FUNDAMENTAL RELATIONS BETWEEN SOIL STRUCTURE AND TREATMENT.

By N. G. CASSIDY, M.Sc., A.A.C.I.*

TABLE OF CONTENTS.

	Page.
Summary	89
Introduction	90
Scope of the Work	91
Materials	91
Methods	93
Keen-Raczkowski Test	93
Modification for Cases Where Contraction in Volume Occurs on Wetting	93
Relative Percolation Rate	96
Hardness Test	98
Calibration of Hardness Scale	100
Dispersion of Silt and Clay	103
Treatments	103
Dry Working	103
Wet Working	104
Partial Sodium-saturation	104
Cropping to Beans	104
Reference Standard of Structure	106
Field Information	106
Clods	106
Evidence of Field Officers and Farmers	107
Results	107
Discussion	107
References	111
Appendixes	112

SUMMARY.

Five soil types from coastal Queensland, representing humid tropical, relatively dry tropical, and relatively dry sub-tropical districts, were examined for changes in structure induced by various kinds of physical treatment.

In order to assess change in structure, measurements were made of relative percolation rate, maximum water-holding capacity, total pore space, hardness of soil crust, and dispersion of silt and clay. Treatments applied were dry working, wet working (at moisture equivalent and at sticky point), cropping to beans, partial sodium-saturation and some combinations of these.

All treatments caused responses in some of the properties measured, indicating the dynamic nature of the soil's physical state. The same treatment had varied effects on different soil types, showing that in the present state of our knowledge the correct cultivation of each soil type is a separate problem.

* Formerly Analyst, Bureau of Sugar Experiment Stations.

Water-holding capacity is not a constant for each soil type, but undergoes positive and negative changes of considerable magnitude depending on the method of manipulation. Pore space varies in a similar fashion but to a lesser degree.

Soil puddling caused by ingress of sodium ions is not identical in its physical effects with puddling induced by mechanical means.

The best treatment for restoring a hard-crusted soil surface to normal is continued wetting and drying.

The Bundaberg red volcanic loam showed a phenomenal increase in percolation rate after wet working at or a little above its moisture equivalent.

Partial sodium-saturation appears to render some soils particularly sensitive to subsequent mishandling.

The methods evolved in this work could be usefully applied in characterizing soils whose physical properties are not known from field experience.

INTRODUCTION.

Although reliable methods are available for estimating the plant nutrients in a soil, the same cannot be said for the evaluation of its physical condition, and consequently the complete agricultural value of the soil cannot be adequately determined in the laboratory. This limitation can be especially hampering when, as with virgin lands, there exists no previous field experience upon which to form an opinion as to the behaviour of the soil under cultivation. When irrigation of such lands is contemplated the problem becomes greater. The paucity of sound methods for assessing the physical characteristics of a soil is probably due, in the main, to two factors. Firstly, the costs of cultivating the soil are regarded as unavoidable expenditure, and the extra costs of struggling with an intractable structure induced in the soil are "unseen" costs and come to be regarded as equally inevitable. The fertilizer necessary for producing a crop of sugar cane, for example, may cost no more than is expended on cultivation operations, but whereas fertilizer is an obvious charge against crop returns, costs of cultivation and especially excessive costs are not seen in this way, particularly where the farmer does the work of cultivation himself. Secondly, apart from the absence of an economic factor acting for the encouragement of work on soil structure, the present lack of good physical tests is due to the need for more knowledge of fundamental facts. The discoveries of cation exchange and phosphate fixation have given a background of fundamental principles upon which the student of nutrient deficiencies may work, but no adequate background exists in the field of soil physics. The investigations reported in the present paper were concerned with the collection of fundamental data, in order to further the time when theories of soil structure will be more the natural development from ascertained facts than they often are at present. It has seemed to the writer that the present-day tendency is to study what constitutes good soil structure (usually attained by tremendous additions of organic matter and

demonstrated by measurements of the size of water-stable aggregates) and to neglect both the opposite condition of bad structure and the study of those soil properties, such as pore space and permeability, which are directly affected by changes of structure. As an illustration of this, a search of the literature failed to reveal a single complete definition, based on experiment, of a "puddled" soil. As a consequence of the tendency referred to, the general conclusion is reached that if the soil is kept well supplied with organic matter the number of large aggregates will be high and the physical condition of the soil satisfactory.

Under tropical and sub-tropical conditions it is not practicable to keep the organic matter content high, so in these cases the advice becomes a counsel of perfection; moreover, such an outlook does not help in elucidating the changes which take place in the nature of the soil when it undergoes a change in structure.

SCOPE OF THE WORK.

In the present investigation various mechanical treatments were applied to soils and an endeavour was made to measure the effects of these treatments upon five properties of the soil—the relative percolation rate; the maximum water-holding capacity; the total pore space; the hardness of the soil surface upon drying; and the degree of dispersion of the silt and clay particles.

The significance of these properties will be realised when it is considered that irrigated tropical and sub-tropical soils should (*a*) possess a high degree of permeability, (*b*) be capable of storing a large amount of water, and (*c*) retain a friable surface condition upon drying under a hot sun.

The implications of such desiderata will be considered further under the discussion of the individual tests.

MATERIALS.

The investigation was commenced using in part ordinary laboratory soil samples, although it was suspected that the normal preparatory treatment necessary for soil fertility studies might be much too severe for the projected work. The normal treatment for fertility studies in the laboratory of the Bureau consists in air-drying a sample of about five pounds of soil until it is in the best condition for passing through a 2 mm. sieve, and then continuing the drying (in a thin layer on a metal tray) until there is no longer any visible change taking place. Sometimes the sample is already dry when received and it is then crushed using a wooden hand-roller and an iron baseboard. When the soil sample is very dry considerable pressure is necessary, and the preliminary studies showed that this treatment may entirely alter the physical condition of the soil; all the later work was therefore performed on bulk samples, of about one bushel each, which were taken in the moist condition and given as little crushing treatment as possible. For this reason the values given in the tables for the earlier and later samples of the same soil type do not always agree. In two cases

virgin samples of the soil type under consideration were obtained, in order to separate inherent tendencies from mere effects of past workings. The soil types used are described in Table 1.

Table 1.

DESCRIPTION OF SOIL TYPES USED IN LABORATORY EXPERIMENTS.

Soil.	Colour and Texture.	Lab. No.	pH.	Total Nitrogen.	Mechanical Analysis.				Moisture Equivalent.	Optimum Moisture.	Remarks.
					Coarse Sand.	Fine Sand.	Silt.	Clay.			
				%	%	%	%	%	%	%	
Cairns red schist	Red loam ..	6351	4·8	0·12	7·7	50·5	16·4	25·4	15·2	19	
Russell River alluvial	Yellowish brown silty loam	2412	5·0	0·16	8·0	37·6	23·9	30·5	23·8	28	
		6352	4·7	0·21	10·1	20·5	31·1	38·3	28·6	24	
Burdekin alluvial	Dark grey silty clay loam	4825	6·0	0·18	13·9	40·6	20·9	24·6	22·5	15	Virgin soil
		6350	5·8	0·11	2·6	54·0	19·7	23·7	21·4	13	
Bundaberg red forest	Red sandy loam	2411	5·5	0·10	31·6	24·2	14·1	30·1	13·5	13	
		6353	5·4	0·11	46·4	23·8	6·2	23·6	11·3	10	
Bundaberg red volcanic	Red loam (lateritic)	6354	7·1	0·43	22·6	0·5	23·8	44·1	31·5	25	Virgin soil
		2410	6·3	0·20	14·6	10·2	15·7	59·5	25·0	25	
		6355	6·0	0·17	12·8	8·6	18·4	60·2	27·1	25	

Many cultivated phases of the Lower Burdekin alluvial were also examined and some further tests were made on the series of partially sodium-saturated soils used by Cassidy (1944) in a previous soil study. Meteorological data for the four localities from which the soil types were obtained are given in Table 2. The first two localities represent the humid tropics, the third the

Table 2.

METEOROLOGICAL DATA RELEVANT TO THE SEVERAL SOIL TYPES.

Locality.	Latitude (Degrees South).	Mean Annual Rainfall (Inches).	Mean Annual Temperature °F.		Relative Humidity (Per Cent.).
			Maximum.	Minimum.	
Cairns	17	89	85	68	78
Russell River	17½	162	82½	65	77
Burdekin Delta	19½	41	84	64	62
Bundaberg	25	44	80	60	64

relatively dry tropics, and the last the relatively dry sub-tropics. Although the latter two localities experience frosts, there are only about five per year and their effect on the physical condition of the soil can probably be neglected. The rainfall, however, in all areas may occur with tropical intensity, a few instances of 10 inches of rain in 24 hours having been recorded for the two more southern localities and many such for the others.

Since the Lower Burdekin and Bundaberg soils are irrigated, it is clear that all the soil types under consideration are subjected to a considerable impact of water, whether as heavy rainfall alone or as rainfall and furrow-irrigation

combined. In the present study the methods of investigation take cognizance of this fact, for it is of no avail to measure carefully some temporary condition of the soil if the stability of that condition to the impact of water is not also determined.

METHODS.

The methods used have been simple and in this way many more data have been collected than would have been possible using some of the involved apparatus described in the literature. Although these methods have not yet reached the highest desirable degree of precision, they have been justified by the results. The use of the original improperly prepared samples of soil previously referred to has sometimes clouded the issue when comparisons are made with the later and more carefully prepared samples; but, on the other hand, the difference in method of preparation has sometimes simply provided a comparison between a control and a dry working "treatment" and the results have been indicated accordingly (see Appendix A, where the original sample No. 2410 is in effect the dry worked treatment of No. 6355).

Reference has already been made (Cassidy, 1944) to certain of the methods used. The simple apparatus employed is shown in Plate 1.

Keen-Raczkowski Test.

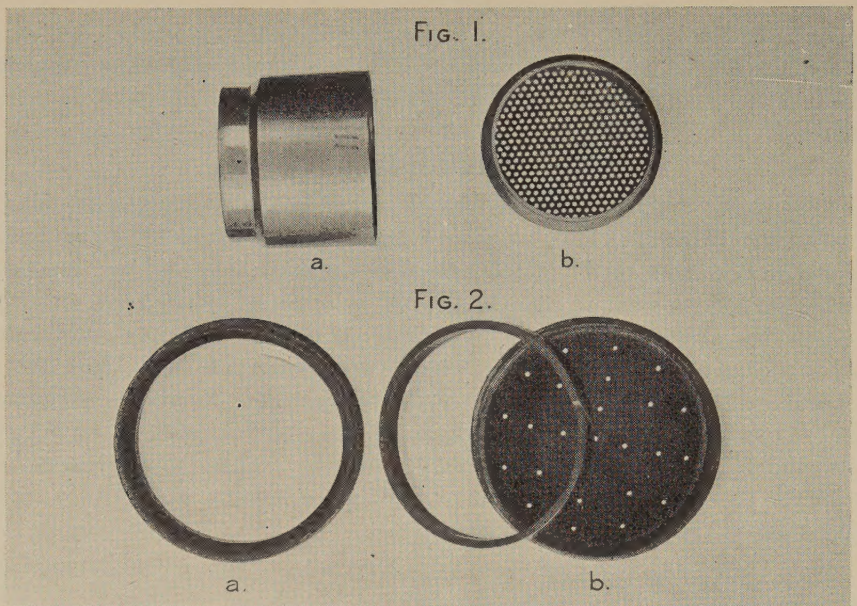
This was carried out in Coutts' (1930) modified boxes, with the additional modification that the soil was passed through a 2 mm. sieve only, instead of through the 100 mesh specified, in order to avoid changes of structure due to fine sieving. Even the 2 mm. sieving was shown to have some effect on soil properties, and it was used as little as possible. After sub-samples of the soils had had any treatment involving moistening with water they were allowed to come to optimum moisture content (i.e., the best condition of friability as determined by feel) and then broken down gently with the fingers. In cases where this still resulted in a lumpy condition and prevented the surface of the box from being struck off level, a small quantity of soil was very gently ground in a mortar and used as a thin finishing-off layer. A modification was also introduced for cases where contraction of volume occurred on wetting, as for certain puddled soils, and when a soil at optimum moisture was used as original sample. This modification is given in detail below.

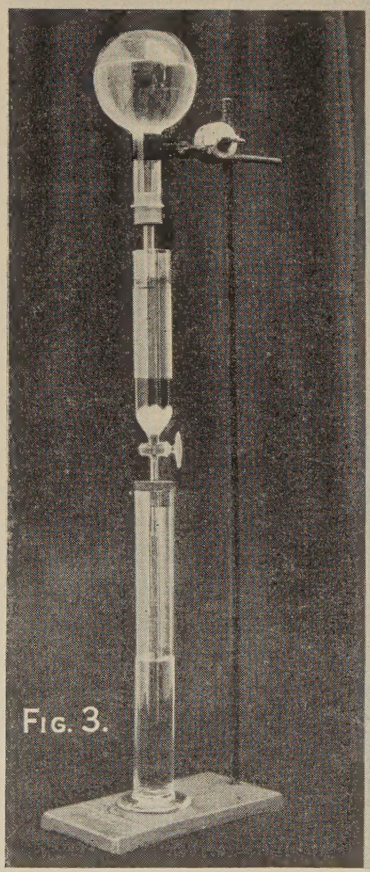
Modification for Cases where Contraction in Volume Occurs on Wetting.

Select a sample of sand which retains its original volume on wetting. A screened faction 0.5-1.0 mm. is convenient and will have negligible hygroscopicity.

1. After making weighings (a) and (b) in the usual way, immerse the dish in ¼ inch water as usual, until the soil is saturated. To obtain this state correctly, the dish must be withdrawn from the water and shaken gently to fill the gap around the walls of the dish with saturated soil and not (as would otherwise be the case) with water. Then make weighing (c) of dish + saturated soil.

2. Pour dry sand from a small weighed beaker into the Keen-Raczkowski dish, and strike off with a spatula to remove the excess. Dry the excess (if it has come into contact with moisture) and return it to the beaker. Find by difference the weight of dry sand (Ws) used.





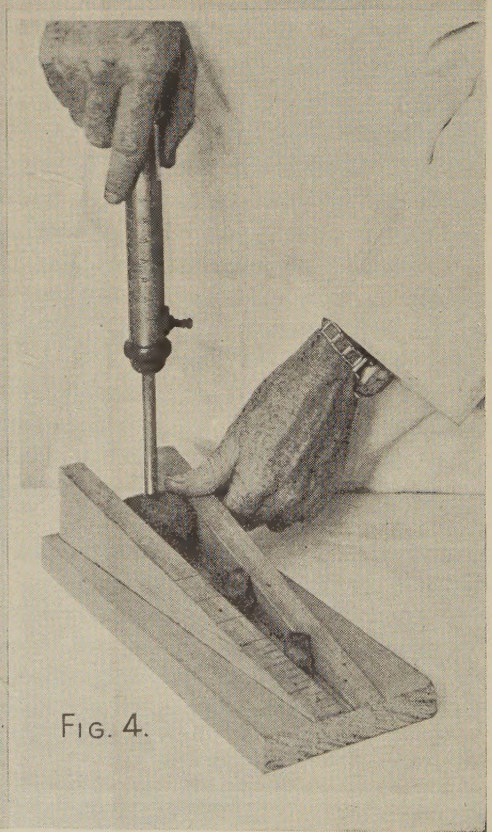


Plate 1.

3. Divide Ws by the Sp.Gr. of the sand to find its volume (Vs), and multiply Ws by the water capacity (Cs) of the sand to give the amount of water WsCs which this layer of sand can hold.

N.B. The constants of the sand are determined by making a Keen-Raczkowski test on it in the ordinary way.

4. Again immerse the dish and when the soil and sand are saturated make weighing (d). Proceed then in the usual way.

Calculations.

$$\text{Pore Space} = \frac{(e - a) - (e - a - Ws)\ 100}{V - Vs}$$

$$\text{Sp. Gr.} = \frac{e - a - Ws}{V - Vs - (d - e - WsCs)}$$

$$\text{Vol. Contraction} = \frac{Vs}{V} \times 100$$

As an indication of the reliability of Keen-Raczkowski data, Table 3 shows the difference in water capacity necessary for significance at odds of 20 : 1, when duplicate determinations are made on both the normal, air-dried soil and on the same soil after a treatment has been applied. It will be appreciated that whenever more than duplicate tests have been made, a smaller difference will be significant, depending on the actual number of replications. Thus in Appendix A Lab. No. 2412, for six tests on the normal, air-dried sample and two on any "treated" sample, the difference in water capacity required for significance will only be 4.2 per cent. as against 5.2 per cent. when but two measurements are made.

Table 3.

SIGNIFICANT DIFFERENCES IN WATER CAPACITY DETERMINED BY KEEN–RACZKOWSKI METHOD

Soil Type.	Laboratory Number.	Significant Difference (with duplicate determinations and odds 20 : 1).
		%
Burdekin alluvial ..	4825	±2·3
	6350	±5·0
Russell River alluvial	2412	±5·2
	6352	±1·7
Bundaberg red forest	2411	±3·8
	6353	±5·4
Bundaberg red volanic	6354	±4·8
	2410	±3·3
	6355	±2·2

DESCRIPTION OF PLATE 1.

Apparatus used for making tests. Fig. 1, Moisture equivalent dish, showing (*a*) general shape, and (*b*) perforated bottom. Fig. 2. Keen-Raczkowski dish, showing (*a*) filter paper disc and split ring in position, (*b*) split ring removed from dish, and view of perforated bottom. Fig. 3. Apparatus for determining relative percolation rate. Fig. 4. Hardness instrument in use.

The values of most interest are those for water capacity and pore space. It should be noted that pore space is expressed as a percentage by volume. It represents the total air space in the soil. Results are quoted without comment and no attempt is made to divide the total pore space into hypothetical capillary and non-capillary parts. The water capacity represents the maximum amount of water which the soil can retain for a brief period (there is usually no loss by drainage during the weighing operation) when the box has been standing in $\frac{1}{4}$ inch of water. The box itself is $\frac{3}{4}$ inch deep. Although this value for water-holding capacity is obviously too high for temperate climates and long drainage periods, there is much to recommend its use in place of lower values of the order of the moisture equivalent when heavy rain or furrow irrigation is the means by which the soil receives its moisture, and when high evaporation and high transpiration tend to prevent conditions of slow percolation from being established in the soil.

Relative Percolation Rate.

This simple test of permeability of the soil to water was devised not as a measure of absolute values but as an indication of their relative order. The original procedure (Cassidy, 1944) has been modified by using a Mariotte bottle to maintain the head of water at constant level, and by adding the soil sample to the leaching funnel so that it falls gently at the junction of the funnel and the water surface, when there is a depth of 10 cm. of water in the funnel. The cotton-wool plug and tap funnel are as previously described. By means of these standardizations of procedure better replications of results were obtained, and it is only with very high percolation rates that large differences between replications are likely to be obtained. Duly and Domingo (1944), using a somewhat similar technique, showed that a change of temperature of 30 deg. F. did not significantly affect the results. The method is clearly one for measuring saturated flow and using soil which has been disturbed from its natural state. The latter condition is necessitated by the nature of the investigations reported in this paper, and the former is the only one applicable to the climatic and field conditions concerned. The data are expressed in millilitres per minute and records were continued in some cases up to three hours after commencement. As a rule the 30 to 60 minute period proved satisfactory in providing a relative percolation rate characteristic of the soil and its particular condition at the time of the experiment. By taking this time period zero errors were eliminated; moreover, the normal decrease in rate due to washing out of soluble salts had not usually commenced.

Christiansen (1944) has shown that high initial permeability, decreasing with time, is characteristic of a de-aerated soil; whilst low initial permeability, increasing for several days, is characteristic of soil containing entrapped air. In the present paper, low values in a series of replicates are therefore more likely to be suspect than are the high ones, and it is felt that the removal of air when adding the soil sample through a water layer may yet be made more complete by further modification of the present technique.

Table 4.

HARDNESS OF SOIL CRUSTS ENCOUNTERED IN A CONTINUOUS SEQUENCE OF TREATMENTS.

No. of Test in Sequence.	Sub-irrigated to Saturation, and Drained 10-15 Minutes, between Tests.		No. of Series.	Burdekin alluvial.	Russell River alluvial.	Bundaberg red forest.	Bundaberg red volcanic.	Total Units of Hardness.
	Mechanical Treatment (given prior to drying).	Method of Removing Water.						
1	Nil	Centrifuged at 100 g; then dried in oven	1	2	1	< 1	2	5·5
	Nil		2	2½	1¼	< 1	1½	6
	Nil		3	3	1½	< 1	1½	6·7
2	Nil	Dried in air, then in oven	1	1⅓	< 1	< 1	< 1	3·3
	Nil		2	2	< 1	< 1	< 1	4
	Nil		3	2	< 1	< 1	< 1	4
3	Nil	Centrifuged at 1,000 g; then dried in oven	1	2½	1	< 1	< 1	5
	Nil		2	2	1	< 1	< 1	4·5
	Nil		3	2	1	< 1	< 1	4·5
4	Nil	Centrifuged at 1,000 g; dried in air (2½ days), then in oven	1	2	1	< 1	< 1	4·5
	Pressed lightly		2	6	2½	3	4	15·5
	Pressed heavily		3	12	7	8	7	34
5	Nil	Centrifuged at 500 g; then dried in oven	1	1¼	< 1	< 1	< 1	3·5
	Nil		2	4	2	1	< 1	7·7
	Nil		3	9	4	2⅓	1	16·3
6	Pressed heavily	Centrifuged at 500 g; then dried in oven	1	14	7	9	3	33
	Pressed lightly		2	11	6	3	3	23
	Nil		3	7	2	1	1	11
7	Nil	Dried in air and sun ..	1	9	4	2¾	1	16·5
	Nil	Dried in air (2½ days), then in oven	2	7½	5	2	1	15·2
	Nil		3	6	2	1	1	9·7
	All dishes emptied out, and the dry, lumpy soil returned to the respective dishes and sub-irrigated. The wet soil was shaken till it subsided to an even surface.							
8	Wet soil shaken to an even surface	Centrifuged at 250 g; then dried in oven	1	5·5	4·7	3	1	13·9
			2	4	3·4	1·7	1	9·8
			3	2	3	1	1	6·7
9	As above ..	As above ..	1	4·4	3	1·5	1	9·6
			2	5	2·4	1·2	1	9·3
			3	3·7	2	1	1	7·4

Table 4—*continued.*

HARDNESS OF SOIL CRUSTS ENCOUNTERED IN A CONTINUOUS SEQUENCE OF TREATMENTS—*continued.*

No. of Test in Sequence.	Sub-irrigated to Saturation, and Drained 10-15 Minutes, between Tests.		No. of Series.	Burdekin alluvial.	Russell River alluvial.	Bundaberg red forest.	Bundaberg red volcanic.	Total Units of Hardness.
	Mechanical Treatment (given prior to drying).	Method of Removing Water.						
10	Pressed heavily with turning motion	Centrifuged at 250 g; soils tipped out, then returned to dishes and worked with rubber stopper down to level surface again (*see* "Treatment"). Dried in oven	1	*c* 30	13·6	21	21	>86
			2	>30	13	20	20·6	>84
			3	>30	14·2	19·4	19·8	>83
11	Nil	Dried in air, then in sun and oven	1	14	7	5	9	35
	Nil	Dried in sun, then in oven	2	22	7	3¾	10½	43¼
	Nil	Dried in oven	3	15½	5	3	2	25½
12	Wet soil shaken to an even surface	Dried in air, then in sun and oven	1	13	9	5½	8	36
		Dried in sun, then in oven	2	16	9	6	6	37
		Dried in oven	3	17	10	6½	2	3€

Note: g = acceleration due to gravity.

Hardness Test.

This test, which has also been previously described (Cassidy, 1944) was further developed to shorten the necessary drying time. In order to do this the subirrigated samples of soil were centrifuged in their containers as for an ordinary moisture equivalent determination. (If required, the determination of moisture equivalent was completed by making the necessary weighings in the original dishes, applying a correction for the water held by the filter paper disc). Table 4 gives a continuous record, in chronological order, of the treatments applied to a series of soils and of the hardness of the soil surface after treatment. The numerical values are mean readings on the hardness instrument, four or more individual readings usually being obtained before the breaking up of the soil cake prevented any more readings being taken.

The results show clearly that:—

1. The hardness test indicates changes produced by the various soil treatments given.
2. Centrifuging and oven drying are permissible expedients. (This is later modified for certain Burdekin soils).
3. Pressing the moist soil increased the hardness according to the amount of pressure applied.
4. Wetting and drying alone will cause the recovery of a crusted soil, but in severe cases several repetitions of the treatment are required.

The hardness test thus evolved was used to determine the effect of other treatments upon the soil. It was then found that for certain Burdekin soils conclusion 2 above does not apply. The action of centrifuging the wet soil is sufficient to give a considerably higher value for the resultant hardness when cultivated Burdekin soil, and especially soil that is partially sodium-saturated, is used. The results shown in Table 4 were obtained with virgin Burdekin soil.

In Table 5 are shown segregated the effect due to draining the centrifuge dishes and that due to the action of centrifuging. It will be seen that it is immaterial whether or not a 10-15 minute drainage period is allowed before

Table 5.

SHOWING HOW CENTRIFUGING (BUT NOT DRAINING) AFFECTS THE HARDNESS VALUE RECORDED FOR CERTAIN BURDEKIN SOILS.

Lab. No.	Phase of Burdekin Alluvial Soil.	Drained Only.	Centrifuged Only.	Drained and Centrifuged.
4825	Virgin soil. Clods very lightly crushed	3·9	4·2	4·0
1229	Cultivated soil	5·0	13·3	12·9
4826	Cultivated soil	1·5	11·6	13·2
1219	Cultivated soil	9·4	10·1	17·5
3635	Cultivated soil	10·4	14·7	14·0
3637	Cultivated soil	8·6	13·8	12·7
Average value for the Cultivated soils		7·0	12·7	14·1

centrifuging, but the action of the centrifuge does cause a higher hardness value to be registered; presumably this is due to the working suffered by the soil sample as it settles under the centrifugal force. Table 6 shows the influence of centrifuging at a force of 250 times gravity and then at 1,000 times gravity. The difference between the centrifuged and the non-centrifuged samples is greater in the latter case than in the former, further indicating that, for these soils, the act of centrifuging constitutes a "treatment." It is interesting to note that in this phase of the work, where the same samples in the same dishes were used, being centrifuged first at 250g and then at 1,000g. the

Table 6.

SHOWING THE INCREASES IN HARDNESS DUE TO TWO DIFFERENT RATES OF CENTRIFUGING OF CERTAIN BURDEKIN SOILS.

Lab. No.	Phase of Burkedin Alluvial.	Sub-irrigated and Drained.					
		Centrifuged at 50 g.	Not Centrifuged.	Increase Due to Centrifuging.	Centrifuged at 1000 g.	Not Centrifuged.	Increase Due to Centrifuging.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
4825	Virgin soil. Clods crushed	6·8	6·9	−0·1	4·4	1·9	2·5
1223	Cultivated soil..	5·0	4·1	0·9	3·7	1·0	2·7
1229	Cultivated soil..	9·7	7·2	2·5	10·0	2·2	7·8
6229	Cultivated soil..	5·7	4·5	1·2	2·1	<1	—
..	Cultivated soil..	11·3	10·4	0·9	8·8	3·8	5·0
Average for all soils ..		7·7	6·6	1·1	5·8	1·8	4·0

absolute values are lower in columns 5 and 6 than in columns 2 and 3 because of the intervening wetting and drying which has taken place. The Burdekin soils which showed increased values of hardness after being centrifuged were those soils which owing to partial sodium-saturation or bad management, or both, readily gave high values under other methods of handling. It is a moot point whether, in determining the hardness values of such soils, the tendency of the normal conditions of the experiment to produce high values in some soils should not be allowed to take its course, since the super-sensitiveness of these soils will give rise to this result very readily under field conditions. Occasionally soil types other than the Burdekin alluvial gave increased hardness values after centrifuging, but the increases were of a lower order than with the Burdekin soils.

Calibration of Hardness Scale.

It is of interest to know the actual pressures exerted by the hardness instrument. By pressing with the point of the instrument on one scale pan of a balance in order to equalize various weights loaded on to the other pan, the curve shown in Figure 1 was obtained. An instrument reading of 26 divisions corresponds to a pressure by the needle of about 1,000 atmospheres, or 15,000 lb., per square inch. Up to this reading the relationship is linear. The calibration curve did not change during 12 months' usage. The limit of the instrument was about one and a-half times this pressure, the curve showing rapid increases of pressure for small increases in readings at the end of the range.

In preliminary experiments on the hardness developed in soils upon being mishandled it was found that wet working by kneading the soil with the fingers often produced a condition on drying that was impenetrable to the soil penetrometer. As it is desirable to be able to distinguish between one soil condition and another (however bad they may be), and also to work somewhat nearer to the treatment experienced by the soil in the field, another

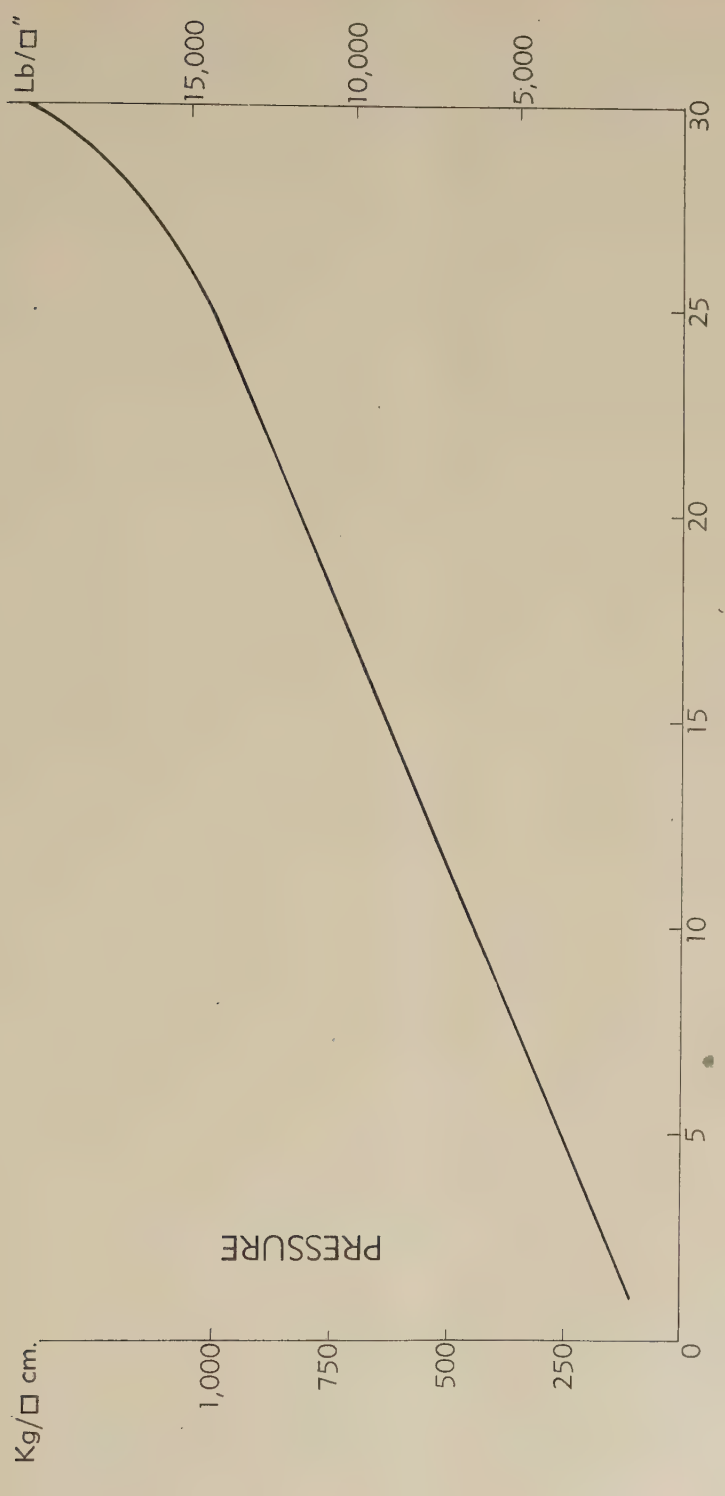


Figure 1.

Showing calibration curve of hardness instrument.

method of mishandling the soil was adopted, bringing the hardness values within the range of the instrument. This treatment consisted in centrifuging the samples exactly as for a moisture equivalent determination, and then subjecting them whilst at this moisture content to pressure, with a slight turning motion, applied through a rubber stopper. The stopper just fitted the moisture equivalent cup containing the soil, but allowed freedom for turning. In applying the test one of a pair of cups was placed on each pan of a heavy duty balance of the type known as "druggist's scales." To one side was added the requisite weight of approximately 5 kilograms. Pressure was then applied manually to one soil surface through the medium of the rubber stopper until the balance just assumed the equilibrium position; at the same time the stopper was turned through a right angle. This procedure was carried out five times. The whole treatment will hereafter be described in this paper by the terms "pressed heavily" or "heavy pressure." The pressure exerted on the soil by this heavy pressure treatment is 500 g. per sq. cm. or approximately 7 lb. per sq. inch. The wheel pressures of a number of crawler-type tractors were found from specifications to be 5-6 lb. per square inch, whilst the air pressure in rubber-tyred tractors is commonly 10-15 lb. per square inch. It is therefore clear that the heavy pressure treatment given in these laboratory experiments is of the same kind and of the same order as that experienced by the soil when, say, a rubber-tyred tractor turns on a headland. It is of interest to note that such heavy pressure on a soil which is in particularly bad physical condition may induce in the final dried surface a hard crust which requires 2,000 times the original pressure to break through it.

A second treatment, described by the terms "light pressure" and "pressed lightly," was also made use of and this was simply one-tenth of the heavy pressure value. It was used in those cases where the particular laboratory treatment given to the soil left it in a lumpy condition unsuitable for the application of the penetrometer test. Appendix C shows that this light pressure, applied even at the relatively high-water content of the moisture equivalent, does not unduly increase the hardness readings. In fact, where the original untreated values were high, the additional wetting and drying involved in subjecting the samples to "light pressure" treatment was sufficient to cause an actual reduction in the readings. It may be noted in passing that this method of working the soil is restricted to the small amounts held in the centrifuge cups and is therefore not suitable for the treatment of large samples.

For the preparation of such samples another, more empirical and less reproducible method, had to be used. It consisted in weighing 700-800 g. air-dry soil into a 9-inch diameter crystallizing dish, adding gradually from a burette enough distilled water to bring the total to the moisture equivalent, meanwhile incorporating the water with the soil by stirring with a 9-inch steel-bladed spatula. When the soil had assumed a uniform colour it was worked with 100 strokes of the spatula, moving the blade with a sliding motion across the soil lying under it. The blade was scoured clean between strokes, with a

smaller spatula, as required. When smaller samples of worked soil were needed the number of strokes was reduced somewhat proportionately to the weight of soil, with a minimum of 20 strokes for a 20 g. sample. This treatment is referred to in the tables as "worked at moisture equivalent," "worked at 30 per cent. moisture," etc. It will be realized that the effects produced on different sized samples thus treated will be the same in kind rather than in degree.

Dispersion of Silt and Clay.

The remaining physical property of the soil measured in these studies was the dispersion of the silt and clay particles. The ordinary mechanical analysis of the soil, with complete dispersion, was carried out according to the International Method (Robinson, 1933). The soil was then subjected to the same pipette method of analysis, but without any pretreatment with hydrogen peroxide and hydrochloric acid. In other words, the distribution of clay, silt, and sands was determined without altering the state of dispersion existing in the particular sample on hand. This, of course, constitutes an inverse aggregate analysis in which the attention is fixed on the small particles and not, as is usual, on the large aggregates. The percentage dispersion was then calculated by dividing the actual silt and clay present in the particular sample by the total silt and clay in the completely dispersed soil. This determination was made because of the prevalent idea in the literature of soil science that a soil in bad physical condition is simply a soil with its clay dispersed. In this paper it is shown that, although saturation with sodium will cause poor physical condition associated with dispersion of the clay, mechanical working of a soil at an unfavourable moisture content may cause little change in its dispersion whilst degrading its physical structure in no uncertain manner as shown by, say, its percolation rate or its hardness value. It therefore becomes clear that dispersion (and especially dispersion of the clay alone) is not in itself a sufficient explanation of poor physical condition in soils. If percentage dispersion had been defined in terms of clay only, instead of silt plus clay, partial sodium-saturation would have been the only treatment which produced any considerable amount of dispersion; and the identification of all cases of poor physical condition with a high degree of dispersion of the clay would appear still more erroneous.

TREATMENTS.

The treatments used in this work were (*a*) dry working; (*b*) wet working; (*c*) partial sodium-saturation; (*d*) cropping to beans; and (*e*) some combinations of these.

Dry Working.

This treatment merely consisted in grinding the air-dry soil in a porcelain mortar, using no more pressure than was readily applied by a "pencil grip" on the pestle instead of the customary fist grip. Some idea of the fineness of the soil resulting from this treatment may be gained by referring to the fourth column in Table 7.

Wet Working.

The methods of wet working have been explained, *inter alia,* on pages 102-103.

Partial Sodium-saturation.

The partially sodium-saturated soils of a previous investigation (Cassidy, 1944) were used in this work. These soils contained no soluble salts, the latter having been removed during the preparation of the soils.

Cropping to Beans.

Three of the soil types—the Burdekin alluvial, the Russell River alluvial and the Bundaberg red forest soil—were cropped to beans in order to determine the effect of root growth on the soil. At the same time the effect of dry working these soils was combined with the straight-out influence of the legume. Five-inch or 6-inch unglazed pots, painted grey on the outside to reduce evaporation and maintain soil temperature, were used. Sufficient air-dry soil of numbers 4825, 2411, and 2412 to give a kilogram of soil at optimum moisture was employed. The requisite amount of moisture was gently incorporated with the normal air-dry soil in one case and with the dry-worked soil in the other. The moistened soils were transferred to tared pots and the pots were weighed. These weights were used when adding water to restore loss by evaporation, and when transpiration became important a correction was made for it. Six seeds of the Brown Beauty variety of French beans were planted in each pot. The seeds were planted at a depth of $\frac{3}{4}$ inch and none failed to germinate. The experiment was continued for nine weeks after planting, and at that time, although germination and growth had been very slow owing to the cool weather prevailing, the most advanced plants were bearing young beans. During the trial the soils were never allowed to approach the wilting point for very long before water was added; in this way the surface layer suffered wetting and drying about 35 times during the course of the experiment, and this may have had some effect on the "pot" soil samples as a whole, but, of course, not as between the members of a pair. Water was always added gently to the normal soils, but without care to the dry ground ones.

Owing to an error the moisture content of the Bundaberg red forest soils was kept too low in the early part of the experiment, and this delayed growth in these two pots very considerably. As the cotyledons emerged the date was noted, and later unwanted plants were removed, leaving two average-sized plants growing in each pot. Towards harvest a small quantity of nutrient solution was added, but as the total addition of ions was less than 15 milli-equivalents per pot, and as each one of a pair received equal amounts, the added salts should have no effect on comparisons of structure. At harvest the plants were washed free of soil, and both green and dry weights of the plants and of the plant roots were obtained. The soils were removed from the pots, mixed, and air dried for testing. Table 7 gives the relevant data.

Table 7.

POT EXPERIMENT DATA.

Soil Type.	Treatment.	Pot No.	Soil Fineness (% less than 1 mm.).	Emergence of Plants.		Green Weights (Grams).		
				Total No.	Time (Days).	Tops.	Roots.	Roots as Percentage of Total.
Burdekin alluvial	Normal, air dried	1	40	6	30	5·80	0·75	11
	Dry ground ..	2	90	4	52	6·42	0·58	8
Bundaberg red forest	Normal, air dried	3	72	5	58	3·34	1·70	34
	Dry ground ..	4	90	5	58	4·27	1·88	31
Russell River alluvial	Normal, air dried	5	51	6	23	13·65	4·62	25
	Dry ground ..	6	80	5	42	7·13	1·83	20

It will be seen that dry grinding prevented the emergence of some of the seedlings and greatly added to the time necessary for the last seedling to come through. In no case was germination at fault, but the cotyledons were held down in the soils of bad structure and in some cases they either snapped off in the hypocotyl region or otherwise failed to break through the soil crust. The proportion of roots to total plant was higher for the normal soil in each case, but

Plate 2.

Bean plants grown on soils subjected to various treatments. (1) Burdekin alluvial; normal, air dried; (2) Burdekin alluvial; dry ground; (3) Bundaberg red forest soil; normal, air dried; (4) Bundaberg red forest soil; dry ground; (5) Russell River alluvial; dry ground; (6) Russell River alluvial; normal, air dried. Note that the order for Pots 5 and 6 has been reversed.

no test of the significance of this was possible in the absence of replicates. The low absolute value of this ratio for the Burdekin soil indicates its inferior physical status, for its plant nutrient content is as high as that of either of the other soil types. Plate 2 shows the plants from the respective pots at harvest.

REFERENCE STANDARD OF STRUCTURE.

One of the conclusions reached in this paper is that, at least in the present state of our knowledge, each soil type needs to be treated as a particular case. It is therefore desirable to adopt a definite condition of the soil as a standard of reference and it is natural to fix on the air-dried state as the one to be so chosen. The normal condition is, then, that which results when the soil has been wetted and then thoroughly air dried. It is, of course, assumed that there is no immediate past history of gross mishandling in any way. That this norm is a good selection is supported by the data in Table 4, which shows that wetting and drying will expunge the effects of any prior treatment that is not too severe, at least as far as the hardness of surface crusts is a criterion. McGeorge (1937) adopted the dispersion in the air-dry state as his zero correction, when expressing dispersion in any other condition as a "degree of puddling." The air-dry state has been adopted in Table 9, which summarizes by plus and minus symbols the effect of various physical treatments on the several properties dealt with in this paper.

FIELD INFORMATION.

Clods.

It is clear from the nature of this investigation that very little of the data can be garnered in the field. For example, it is not practicable to have a field just at the moisture equivalent when it is to be worked, and then to have it dry out completely and be re-worked in the dry state. Still less can these conditions be realized at will in a series of soils, and the samples be brought to a central laboratory without change. It is for this reason that treatments such as dry grinding in a porcelain mortar have been used, though they are not replicas of field operations. They do, however, represent types of mishandling, and it is hoped that better laboratory treatments will be devised in the future. Some field samples have, however, been obtained, including samples of clods formed in three fractious soils. Hardness determinations made directly on the dry clods showed that whilst 3-inch clods tended to be harder than 2-inch and these harder than 1-inch, there was no appreciable difference between the hardness inside and outside the larger clods, except where an implement had left a smooth, glazed surface. In that case there was an extremely hard skin about a quarter-of-an-inch thick, below which the hardness values were somewhat less. Table 8 shows some of the results.

Each figure for the dry clods represents an average of 10 or more readings. It was found advantageous to use a hollow, wooden wedge to hold the clod steady when making these readings (see Plate 1). Measurements recorded in the other columns were made by the standard procedure using moisture equivalent cups.

Table 8.

HARDNESS READINGS ON FIELD CLODS.

Lab. No.	Soil.	Dry Clods. Max. Dimension. 1″	2″	3″	Clods Crushed.	Clods Slaked.	Clods Crushed and Ground.	Clods Slaked; Centrifuged, and Pressed Heavily.
4825	Burdekin alluvial	11	18	..	2·0	9·0	4·8	9·2
6331	Burdekin alluvial	..	28	28	12·6	7·3	26·4	13·6
..	Burdekin alluvial	22	28	28	12·8	9·2	17	22·5

In this case preparation by merely crushing the clods before subirrigating and drying the sample in the standard manner appears to be the best procedure to adopt in assessing the relative hardness of the soils.

Evidence of Field Officers and Farmers.

In order to test the conclusions to which these laboratory experiments have led, a questionnaire was submitted to extension officers, who gave (by collaborating with practical farmers) the experience and the opinions of those closely associated with the cultivation of the several soil types regarding the behaviour of the soils in the field. As a result of the questionnaire the Burdekin alluvial and to some extent the Cairns red schist soil were rated as "sensitive to handle" and the others as more tolerant, indicating no serious conflict between the laboratory findings and practical experience in the field. Some properties, such as water capacity and pore space, cannot of course be evaluated by simple field observations.

RESULTS.

The measurements on each of the soil properties studied are recorded in the Appendixes. These should be consulted for all details, but for convenience Table 9 has been drawn up to provide a survey of the whole field. It should be noted that this table merely provides a resume of the main findings and is approximate only. It is not a simple compression of the data.

DISCUSSION.

The first fact that emerges from a review of the data is that all soil types reacted in some way to any treatment which was used in these experiments. In many cases more than one of the properties measured was found to have undergone a change, and the changes were often of considerable magnitude. The increase in the percolation rate of the Bundaberg red volcanic soil type, due to working at or slightly above the moisture equivalent, was spectacular; for by this mechanical means the normal high percolation rate of the subtropical red loam was increased fourfold, to the equivalent of a light gravel. The treatments to which the soils were subjected were admittedly rigorous in some cases, and they may not reflect very well the action of field operations. It is well known that the effect on the soil of a wooden mouldboard is different

Table 9.

SUMMARY OF RESULTS.

Soil and Treatment.	Water Capacity	Pore Space.	Dispersion.	Percolation Rate.	Hardness.	
Basis of Evaluation.	Change in Normal Value.				Actual Reading of Instrument.	Remarks.
Legend. (Negative Signs show corresponding decreases).	+ = 5% ++ = 10% +++ = 20% ++++ = 40%		+ = 25% ++ = 50% +++ = 100%	+ = ×2 ++ = ×4 +++ = ×8		
Burdekin alluvial—						
Normal values	62	56	40	4	4	
Dry ground in a mortar	− − −	− −	0	− −	10	
Worked at the moisture equivalent	0	+	0	− −	7	Moisture equivalent = 22%
Worked at the sticky point	0	0	+++	− − − −	28	Sticky point = 30%
Cropped to beans in pot experiment	− −	0	−	0	1	
Partially sodium-saturated	− −	0	++	− − −	16	
Ditto; and cropped to cane for 40 years	− − −	− −		0	16	
Ditto; and dry ground	− − −		+++	−	26	
Ditto; and wet worked	− −		+++	− − − −	Impenetrable	
Russell River alluvial—						
Normal values	60	54	24	7	1	
Dry ground in a mortar	++ or −	+	+	−	3	See comments in Appendix A.
Worked at the moisture equivalent	+++			+	4	Moisture equivalent = 28%
Worked at the sticky point	+++	+++	+++	− − −	13	Sticky point = 44%
Cropped to beans in pot experiment	+++	++	−	+	2	
Partially sodium-saturated	++	++	++	−	1	
Bundaberg red forest—						
Normal values	37	45	18	8	< 1	
Dry ground in a mortar	− −	−	++	−	3	
Worked at the moisture equivalent	++	+		++	2	Moisture equivalent = 12%
Worked at the sticky point	+++	+++	++++	− −	7	Sticky point = 22%
Cropped to beans in pot experiment	++++	+++	− −	++	1	
Partially sodium-saturated	+++	+	++	0	< 1	
Bundaberg red volcanic—						
Normal values	60	56	9	8	1	
Dry ground in a mortar	− − −	−	+++	−	8	
Worked at the moisture equivalent	++	+	++	++	1	Moisture equivalent = 26%
Worked at the sticky point	+++	++		−	7	Sticky point = 36%
Cropped to cane for 40 years	− −	0	0	− −	1	
Cairns red schist—						
Normal values	45	50	13	9	1	
Dry ground in a mortar	0	0	+	−	6	
Worked at the moisture equivalent	++	+	++	0	3	Moisture equivalent = 15%
Worked at the sticky point	0		0		21	Sticky point = 34%

from that of a steel one, whilst in these experiments porcelain, glass, rubber, and steel surfaces were all used at different times. Nevertheless, the experiments have further demonstrated the essential dynamic nature of soil in the physical sense. The changing nature of the physical condition of a soil has long been recognized in respect of the dispersion of the fine particles (usually the clay is specified) and also in respect of the hardness of the soil clods. It is also well known that the absorption of sodium ions by the soil results in decrease of permeability to water and in increased hardness of the soil clods. That the physical manipulation of the soil in any way may effect these properties has been given much less consideration, and measurements of such effects appear to be very few.

It is believed that the dynamic nature of the maximum water-holding capacity of a soil has not previously been fully recognized and quantitatively reported. v. Nostitz (1932) recognized the dependence of water capacity upon the particular structure of the soil existing at the moment. He showed the determining influence on water capacity of the actual process of sieving during preparation of the sample; and he found also that pulverizing the soil to reduce the particles to less than 1 mm. (prevailing soil moisture not stated) increased the water capacity considerably. However, his only conclusion from this work was that water capacity was of no use as a "single value" constant for the appraisal of soils. The water capacity or field capacity of a soil has always been regarded as a fixed quantity, the absolute value for a given soil depending only on the particular method of measurement, provided the chemical composition of the soil remains unchanged, as for example in regard to total organic matter. Shaw and Swezey (1937) stated: "Each soil has a definite capacity for moisture which is inherent in the physical structure and chemical nature of that soil and does not change with season nor with the plant species grown therein." Veihmeyer and Hendrickson (1943), summarizing the known facts, stated the following:—"Structure is the manner in which the soil particles are arranged. It has little effect on the field capacity (for water) but may influence the permeability of the soil to water." Table 9 shows clearly that the static concept of a soil's moisture-holding capacity must be abandoned in favour of a dynamic view which allows of very considerable fluctuations, either positive or negative, from the normal mean value. Table 9 shows how the water capacity, as measured by the Keen-Raczkowski test, may change by either a positive or a negative quantity, and the absolute amount of change may be such as to be of great practical importance. For a complete prosecution of this aspect it would be necessary to determine if physical manipulation of the soil affects that portion of the soil moisture which is not available to the plant—i.e., below the wilting point.

In general the changes of total pore space are similar to those of water capacity but of lesser magnitude. It may well be that these two factors—primarily, water capacity, and, secondarily, aeration—are the ones directly affecting the plant when "a favourable state of aggregation" of the soil is reported.

It will be seen also that the dispersion is increased by many of the treatments, but that the growing of beans caused a definite aggregation of the soil particles.

Percolation rate was decreased by practically all treatments. The phenomenal effect of wet working upon the Bundaberg red volcanic soil is referred to in the comments on Appendix B.

The second outstanding conclusion to be drawn from Table 9 is that the various soil types have responded differently to the same treatments, although the two Bundaberg soils behaved very much alike. This means that, until such time as it is shown that some complete concept is applicable to all soils, each and every soil must be regarded as a separate problem in itself. Certain treatments are shown by Table 9 to have both good and bad effects on the same soil. For example, the water-holding capacity has in many cases shown a very favourable increase due to wet working—a treatment which invariably causes some increase in the hardness of the soil clods. If the latter effect is not very serious, it may become a sound method of management to carry out cultivation at a higher moisture content than would have been countenanced in the past. Clearly there is now a need to test the laboratory findings by field trials in order to work out the best cultural practice for each soil type. Other field treatments of proven value, such as the application of large amounts of molasses to cane lands, should be capable of more accurate assessment by means of the methods described in this paper. One such assessment, for example, has been made on samples from two similar blocks of Burdekin alluvial land, one of which had had an application of molasses in 1942 and the other in 1943. Hardness tests, without centrifuging, were made on these samples, which were originally in poor physical condition, and showed the following values:—

Molasses Applied.	Hardness Determined in 1944.
8 tons per acre in 1942	13.4
5 tons per acre in 1943	5.5

It is clear that a recent application of 5 tons per acre of readily decomposable organic matter is better in its action than 8 tons applied a year previously.

In the discussion of the method for determining the hardness of soil crusts it was shown that wetting and drying is the best corrective for an unduly hard soil crust. In terms of field practice, especially in cases where spray irrigation is used, a procedure is thus indicated for the amelioration of land which has formed hard clods or a crusted surface.

Evidence from other countries shows that now is the time to take stock of the prevailing theories of soil cultivation and to test the value of the methods at present recommended. The former theory that continual cultivation, by maintaining a dust mulch, preserved moisture under hot conditions has been discarded by scientific workers, at least for conditions normally met with.

Other ideas based largely on tradition will need to be closely examined also. Bennett and Allison (1928) after describing the remarkable Matanzas loam of Cuba, which can be cultivated without ill effect at very high moisture content, had this to say of the Bayams type of dense intractable clay:—"Fields were found where knifing and cross knifing to depths of more than 2 feet with subsequent deep plowing and harrowing, at large expense, $60 per acre in one instance, was followed by a flowing together of the disturbed clay into its original state of unfavourable density with the first saturating rains." The possible futility of some operations is also indicated by the conclusions of Cole (1939) who found that "the wetting of the soil, both by winter rains and by irrigation water, brings about changes in the size distribution of aggregates that are often as great as changes brought about by tillage implements." Nor is the unorthodox to be feared, as is shown in the success attributed by Wadham and Wood (1939, p. 180) to a method evolved specifically for dealing with a particular intractable soil in Victoria—i.e., wet ploughing using a skeleton mouldboard.

REFERENCES.

Bennett, H. H., and Allison, R. V. 1928. The Soils of Cuba. Washington, D.C.: Tropical Plant Research Association.

Cassidy, N. G. 1944. Exchangeable sodium and the physical properties of soils. Qld. J. Agric. Sci. 1 (1): 140-56.

Christiansen, J. E. 1944. Effect of entrapped air upon the permeability of soils. Soil Sci. 58: 355-65.

Cole, R. C. 1939. Soil macrostructure as affected by cultural treatments. Hilgardia 12: 429-72.

Coutts, J. R. H. 1930. "Single value" soil properties. III. Note on the technique of the Keen-Raczkowski box experiment. J. Agric. Sci. XX: 407-13.

Duley, F. L., and Domingo, C. E. 1944. Effect of water temperature on rate of infiltration. Soil Sci. Soc. Amer. Proc. 8: 129-31.

McGeorge, W. T. 1937. Some physical properties of puddled soils. Ariz. Agric. Expt. Sta. Bull. 67.

Nostitz, v. 1932. Die Hygroskopizitats-und-Wasserkatazitats bestimmung als Mittel zur stenerlichen Bodenbewertung. Ztschr. f. Pflanz. u. Dung. A 25: 275-87.

Robinson, G. W., 1933. The dispersion of soils in mechanical analysis. Imp. Bur. Soil Sci. Tech. Comm. 26.

Shaw, H. R., and Swezey, J. R. 1937. Scientific irrigation management. Hawaii. Plant. Rec. XLI: 199-279.

Veihmeyer, T. J., and Hendrickson, A. H. 1943. Essentials of irrigation and cultivation of orchards. Univ. of California Agr. Res. Service Circ. 50.

Wadham, S. M., and Wood, G. L. 1939. Land Utilization in Australia. Melbourne: Melbourne University Press.

APPENDIX A.

Keen–Raczkowski Data.

Soil and Treatment.	App. Sp. Gr.	Maximum Water-holding Capacity % (weight)	Pore Space. % (volume)	True Sp. Gr.	Vol. Exp. %	No. of Tests.	Remarks.
Burdekin alluvial—							
Lab. No. 4825—							
Original moist sample	1·04	62·7	55·8	2·21	1·1	6	
Air dried, remoistened, sieved and dried	1·00	60·6	56·4	2·16	2·0	3	
Dry ground lightly	1·10	54·3	56·2	2·20	2·1	2	
Dry ground more severely	1·18	48·2	51·0	2·22	6·6	11	
Worked at sticky point*	0·99	62·4	58·2	2·24	4·1	4	Sticky point = 30%
Worked at sticky point, then dry ground	1·22	46·3	51·6	2·32	6·3	2	
Dry ground, then worked at sticky point	0·98	63·9	58·8	2·23	4·6	2	
Dry ground, then worked at 24% moisture	1·00	62·4	58·8	2·30	4·7	2	
Cropped to beans	1·06	55·3	54·8	2·24	4·2	3	Pot. No. 1
Dry ground ; cropped to beans	1·05	(58·1)	56·9	2·25	3·5	3	Pot. No. 2
Partially sodium-saturated—							
Soil E (8·3% Na)	1·01	64·1	59·0	2·34	3·3	2	
Soil C (12·0% Na)	1·04	59·7	56·7	2·28	4·4	2	
Soil B1 (15·8% Na)	1·04	58·7	55·9	2·24	4·6	2	
Soil D (16·5% Na)	1·11	54·9	53·4	2·26	6·0	2	
Soil A (16·8% Na)	1·08	52·1	(53·0)	(2·22)	−ve	2	
Soil B2 (21·4% Na)	1·07	53·5	54·6	2·28	2·0	1	
Soil F (84·9% Na)	1·17	52·5	52·9	2·47	−2·6	2	
Soil E Dry ground	1·15	49·5	53·8	2·40	2·6	1	
Worked at 28% moisture	1·04	55·7	56·7	2·29	1·7	1	Lateral movement of water almost nil
Soil A Dry ground	1·18	50·6	53·2	2·26	9·9	1	
Worked near sticky point	0·99	54·3	..	..	−ve	1	
Soil B2 Dry ground	1·17	46·8	53·1	2·41	1·3	1	
Worked near sticky point	1·07	..	..	..	−ve	1	
Lab. No. 1219 (14·4% Na)—							Field sample
Normal, air dried	1·09	55·1	54·3	2·17	8·0	2	
Dry ground	1·00	57·8	57·0	2·20	..	4	
Worked near sticky point	1·02	52·8	53·7	2·14	−ve	2	
Field sample	1·13	48·2	50·0	2·17	−ve	2	12·9% Na. Cultivated for cane, 40 years
Lab. No. 6350—							
Original moist sample	0·88	52·3	53·4	2·16	−22·6	4	11% moisture
Normal, air dried	1·11	52·4	52·3	2·20	7·5	10	
Air dried ; cloddy sample	1·16	48·8	51·2	2·24	5·3	4	Small clods were gently crushed
Dry ground	1·16	49·1	50·2	2·20	5·6	2	
Worked at moisture equivalent	0·88	54·8	51·2	1·96	−19·1	4	Moisture equivalent = 21·4%
Russell River alluvial—							
Lab. No. 2412—							
Normal, air dried	1·09	55·5	53·0	2·16	8·4	6	
Dry ground	0·98	61·6	55·5	2·14	2·7	5	
Worked at sticky point	0·91	71·2	62·0	2·22	3·0	2	Sticky point = 40%
Dry ground, then worked at sticky point	0·94	64·1	58·5	2·25	2·0	3	
Worked at sticky point, then dry ground	0·95	58·6	55·1	2·12	−ve	3	
Partially sodium-saturated (18%)	0·94	66·2	57·7	2·14	4·4	2	
Cropped to beans	0·89	70·0	59·3	2·12	1·5	1	Pot. No. 5
Dry ground ; cropped to beans	0·89	70·6	59·2	2·11	2·3	1	Pot. No. 6

* Sticky Point indicates point of maximum stickiness.

APPENDIX A—continued.

KEEN–RACZKOWSKI DATA—*continued.*

Soil and Treatment.	App. Sp. Gr.	Maximum Water-holding Capacity % (weight)	Pore Space. % (volume)	True Sp. Gr.	Vol. Exp. %	No. of Tests.	Remarks.
Lab. No. 6352—							
Normal, air dried	1·03	61·3	56·0	2·10	6·0	10	
Dry ground	0·94	58·8	57·8	2·16	−4·6	2	
Worked at moisture equivalent	0·84	72·1	61·6	2·19	−20·8	2	Moisture equivalent = 28·6%
Worked at moisture equivalent, then air dried	0·94	67·1	57·3	2·06	8·9	2	
Bundaberg red forest—							
Lab. No. 2411—							
Normal, air dried	1·31	35·0	43·9	2·25	4·2	2	
Dry ground	1·37	32·2	42·6	2·32	2·9	3	
Worked at sticky point	1·12	45·4	51·8	2·28	−ve	2	Sticky point = 20%
Worked at sticky point, then dry ground	1·37	34·3	44·0	2·35	4·2	2	
Dry ground, then worked at sticky point	1·06	49·3	54·4	2·25	Nil	3	
Partially sodium-saturated (15%)	1·28	40·9	47·0	2·30	5·6	2	
Cropped to beans	1·10	47·6	51·8	2·30	0·4	2	Pot. No. 3
Dry ground; cropped to beans	1·06	51·0	52·6	2·22	1·3	3	Pot. No. 4
Lab. No. 6353—							
Normal, air dried	1·24	38·7	46·0	2·24	1·0	2	
Dry ground	1·31	35·3	43·0	2·26	−1·0	2	
Worked at moisture equivalent	0·91	(43·6)	48·4	2·17	−23·4	2	Stored 2 weeks
	1·12	44·7	46·8	2·05	4·8	2	Stored 10 weeks
Worked at moisture equivalent, then air dried	1·16	42·8	48·5	2·25	2·2	2	
Bundaberg red volcanic—							
Lab. No. 2410—							
Normal, air dried	1·24	46·5	51·8	2·36	8·2	2	
Dry ground	1·24	44·7	52·6	2·46	5·0	2	
Worked at moisture equivalent	0·93	61·7	58·4	2·38	−20·7	5	Moisture equivalent = 25·0%
Worked at moisture equivalent, then air dried	1·02	60·7	58·2	2·30	3·6	6	
Worked at sticky point, then air dried	0·97	64·7	59·9	2·28	3·1	3	Sticky point = 35%
Worked at sticky point, then dry ground	1·16	48·2	55·8	2·48	2·8	2	
Dry ground, then worked at sticky point	0·95	66·0	59·9	2·25	2·7	3	
Lab. No. 6355—							
Normal, air dried	1·12	60·7	56·2	2·20	6·0	4	Cultivated for cane for 40 years. (Cf. 6354, virgin phase of this soil)
Crushed, dry	1·22	46·8	54·7	2·32	5·6	2	
Worked at moisture equivalent	0·84	68·8	60·3	2·36	−22·9	7	Moisture equivalent = 27·1%
Worked at moisture equivalent, then air dried	0·94	67·5	59·8	2·22	3·8	6	

APPENDIX A—continued.

KEEN–RACZKOWSKI DATA—*continued.*

Soil and Treatment.	App. Sp. Gr.	Maximum Water-holding Capacity % (weight)	Pore Space. % (volume)	True Sp. Gr.	Vol. Exp. %	No. of Tests.	Remarks.
Lab. No. 6354—							
Normal, air dried	1·10	67·3	56·4	2·00	16·5	4	Virgin soil. (Cf. Lab. 6355 for same soil cultivated for 40 years)
Crushed, dry	1·14	65·9	56·9	2·12	17·3	2	
Worked at moisture equivalent	0·94	79·8	64·0	2·27	−8·2	2	
Worked at moisture equivalent, then air dried	0·97	73·5	60·4	2·07	16·8	2	
Dry ground	1·07	71·0	59·6	2·25	11·4	2	
Cairns red schist—							
Lab. No. 6351—							
Normal, air dried	1·23	44·6	49·6	2·30	6·6	2	
Worked at moisture equivalent	0·85	48·9	53·2	2·35	−29·0	2	
Worked at moisture equivalent, then air dried	1·06	53·3	53·0	2·23	2·0	2	
Worked at sticky point	1·16	45·4	(52·0)	2·29	5·0	2	Dried and remoistened
Dry ground	1·24	43·4	49·6	2·35	6·0	2	

COMMENTS.

Burdekin alluvial.

Dry grinding caused a considerable decrease in water capacity, the amount of change being proportional to the severity of the treatment. Pore space was affected to a smaller extent. Wet working had no significant effect on water capacity. When dry grinding and wet working were applied successively the last treatment used expunged the effects of the former treatment. Increasing sodium-saturation gave progressive lowering of the water capacity and, to a lesser extent, of the pore space. Partial sodium-saturation also prevented the attainment of enhanced values by wet working. The treatment of cropping to beans in a pot experiment failed to improve the soil, and the final result was a lower water capacity than before.

Russell River alluvial.

There is a discrepancy between the responses of the two samples to dry grinding. This may be due to the dissimilarity in properties shown in Table 1. Wet working, cropping to beans, and even partial sodium-saturation had favourable effects on the water capacity and pore space.

Bundaberg red forest.

Dry grinding was the only unfavourable treatment as regards water capacity and pore space. Wet working, cropping to beans and partial sodium-saturation each produced substantial increases; whilst in the case of alternate dry grinding and wet working it was the effect of the last treatment to be applied which persisted in the soil.

Bundaberg red volcanic.

Wet working was favourable and dry grinding unfavourable to the achievement of high water capacity and pore space. As with other soil types, the latter treatment expunged the effects of the former.

Cairns red schist.

Wet working at the moisture equivalent (but not at the sticky point) caused an increase in water capacity and pore space. Dry grinding was without effect.

In all soil types except the Burdekin alluvial, wet working enhanced the water capacity and the pore space. Dry grinding had the opposite effect on most of the soils used. The favourable result recorded in some cases of partial sodium-saturation may be a secondary effect from wet handling during the process.

APPENDIX B.

Relative Percolation Rates.

Soil and Treatment.	Percolation Rate ml. per Minute.						Remarks.
	½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	
	%	%	%	%	%	%	
Burdekin alluvial—							
Lab. No. 4825—							
Normal, air dried	4·4	..	..	..	..	..	
Remoistened and sieved	0·8	..	..	..	..	..	
Partially sodium-saturated—							
Soil E (8·3 % Na)	3·6	..	..	..	..	..	
Soil C (12·0% Na)	5·8	..	..	..	..	..	
Soil A (16·8% Na)	0·5	..	..	..	..	..	
Soil D (16·5% Na)	0·2	..	..	..	..	..	
Soil B2 (21·4%)	0·0	..	..	..	..	..	
Soil F (84·9% Na)	0·0	..	..	..	..	..	
Soil C Dry ground	1·6	..	..	..	..	..	
Cropped to beans	6·3	..	..	..	..	..	Pot. No. 1
Cropped to beans ; remoistened and sieved	0·7	..	..	..	..	..	Pot. No. 1
Dry ground ; cropped to beans	5·2	..	..	..	..	..	Pot. No. 2
Dry ground ; cropped to beans ; worked at sticky point	0·1	..	..	..	..	..	Pot. No. 2
Lab. No. 6350—							
Normal, air dried	4·3	4·1	4·0	3·8	..	..	
	3·2	2·5	2·8	2·2	..	..	
Original moist sample	2·5	1·8	1·5	1·2	1·4		
	2·6	1·9	1·6	1·4	1·7		
Original moist sample ; stored 6 months	24·6	22·6	22·1	..	..	..	Soil micro-flora active
	35·7	33·2	31·5	..	..	..	
	26·5	22·8	20·5	20·6	..	..	
Original moist sample ; stored 6 months, then worked at 11% moisture	0·8	0·9	..	..	..	..	
	0·9	0·6	..	..	..	..	
Moistened to optimum moisture	1·7	1·6	1·6	1·3	1·4	1·2	Optimum moisture = 15%
	1·1	0·9	0·7	0·7	0·6	0·5	
Worked at optimum moisture	1·6	3·0	5·7	5·2	..	..	
	1·2	1·0	0·9	0·8	..	..	
	2·4	2·1	1·9	..	..	..	
	2·5	2·1	1·9	..	..	..	
Worked at moisture equivalent	0·6	0·4	0·4	0·3	..	..	Moisture equivalent = 21·4%
	0·5	0·4	0·3	0·3	..	..	
Worked at moisture equivalent, then air dried	3·5	3·0	..	..	..	..	
	8·8	8·3	..	..	..	..	
	5·7	4·4	4·1	3·7	..	..	
	9·9	8·6	8·5	8·1	..	..	
	4·8	4·4	4·3	4·0	..	..	
	5·0	4·7	4·5	3·8	..	..	
Dry ground	2·4	..	..	..	..	..	
	2·4	2·2	2·0	..	..	..	
Other Burdekin alluvials—							
Lab. No. 1219 (14·4% Na)—							
Normal, air dried	1·0	..	..	..	..	..	
Dry ground	0·4	..	..	..	..	..	
Lab. No. 4826 (12·9% Na)—							
Normal, air dried	3·5	..	..	..	..	..	
	2·7	..	..	..	..	..	
	4·2	..	..	..	..	..	
Worked at 18% moisture	<0·1	..	..	..	..	..	

APPENDIX B—continued.

RELATIVE PERCOLATION RATES—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute.						Remarks.
	½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	
	%	%	%	%	%	%	
Lab. No. 6476—							
Normal, air dried	1·6	1·2	..	..	..	..	8 tons per acre molasses in 1942
Lab. No. 6477—							
Normal, air dried	4·7	3·9	..	..	..	..	5 tons per acre molasses in 1943
Russell River alluvial—							
Lab. No. 2412—							
Normal, air dried	11·2	..	..	..	..	..	Early trials
	4·5	..	..	..	..	..	Early trials
	6·6	..	..	..	..	..	
	4·6	..	..	..	..	..	
	4·6	3·9	3·5	3·2	2·8	..	
	6·0	4·0	3·5	3·1	2·9	..	
	8·9	..	..	..	..	..	
	5·8	..	..	..	..	..	
Dry ground	3·1	..	..	..	..	..	
Partially sodium-saturated (18% Na)	2·9	..	..	..	..	..	
Remoistened to 20% moisture, then sieved	3·3	..	..	..	..	..	
Worked at 20% moisture ..	5·9	..	..	..	..	..	
Worked at moisture equivalent, then air dried	6·0	5·0	4·3	..	..	..	Moisture equivalent = 23·8%
	7·0	5·9	5·6	..	..	..	Moisture equivalent = 23·8%
Worked at 40% moisture ..	0·6	..	..	..	..	..	Sticky point = 43%
Cropped to beans	10·1	..	..	..	..	..	Pot. No. 5
	14·7	13·6	12·9	..	..	..	Pot. No. 5
	7·9	6·3	5·5	..	..	..	Pot. No. 5
	11·3	10·4	10·2	..	..	..	Pot. No. 5
	13·0	12·1	11·6	..	..	..	Pot. No. 5
	11·9	10·9	10·8	..	..	..	Pot. No. 5
Dry ground; cropped to beans	5·2	..	..	..	..	..	Pot. No. 6
	10·2	9·7	9·1	..	..	..	Pot. No. 6
	9·5	8·6	8·5	..	..	..	Pot. No. 6
	6·1	5·1	4·2	..	..	..	Pot. No. 6
	10·2	10·2	8·5	..	..	..	Pot. No. 6
	13·6	13·0	12·7	..	..	..	Pot. No. 6
Lab. No. 6352—							
Normal, air dried	7·2	5·8	5·0	4·1	..	..	
	6·5	5·1	4·4	3·8	..	..	
Dry ground	1·9	1·8	1·7	1·6	..	..	
Worked at moisture equivalent	14·3	11·7	10·6	..	..	..	Moisture equivalent = 28·6%
	18·2	15·8	14·3	..	..	..	Moisture equivalent = 28·6%
	23·7	21·4	20·3	..	..	..	Moisture equivalent = 28·6%
Worked at moisture equivalent and air dried	8·0	6·5	6·0	..	..	..	
	8·2	6·4	5·9	..	..	..	
Bundaberg red forest—							
Lab. No. 2411—							
Normal, air dried	3·7	..	..	..	..	..	
	4·5	..	..	..	..	..	
	3·8	3·1	2·8	2·4	1·6	..	
	4·1	3·3	2·9	2·4	2·3	..	
Dry ground	2·3	..	..	..	..	..	

APPENDIX B—continued.

RELATIVE PERCOLATION RATES—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute.						Remarks.
	½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	
	%	%	%	%	%	%	
Partially sodium-saturated (15% Na)	4·0	..	..	..	..	..	
Remoistened to 10% moisture, then sieved	2·6	..	..	..	..	..	
Worked at 10% moisture ..	6·3	..	..	..	..	..	Optimum moisture = 13%
Worked at moisture equivalent, then air dried	6·7	5·0	4·0	..	..	..	Moisture equivalent = 13·5%
	5·6	4·1	3·3	..	..	..	
Worked at 20% moisture ..	1·0	..	..	..	..	..	Sticky point = 21%
Cropped to beans	8·2	6·2	5·0	..	..	..	Pot. No. 3
	14·8	11·0	..	..	..	..	
	9·2	6·8	5·6	..	..	..	
	8·5	7·0	4·7	..	..	..	
	8·3	6·2	5·4	..	..	..	
Dry ground; cropped to beans	4·7	3·2	2·7	..	..	..	Pot. No. 4
	8·2	7·3	6·9	..	..	..	
	10·3	8·7	8·0	..	..	..	
	9·0	..	..	..	..	..	
	12·5	9·4	8·2	..	..	..	
Lab. No. 6353—							
Normal, air dried	9·8	6·7	5·5	..	..	..	
	11·8	9·5	9·7	..	..	..	
	15·2	10·7	7·0	..	..	..	
	9·3	6·6	5·9	..	..	..	
	11·9	8·8	8·6	6·2	..	..	
Dry ground	3·8	3·3	3·0	2·7	..	..	
Worked at moisture equivalent	31·3	25·4	21·2	..	..	..	Moisture equivalent = 11·3%
	27·9	20·2	16·5	..	..	..	
	36·0	..	..	..	..	..	
	37·2	..	..	..	..	..	
Worked at moisture equivalent, then air dried	7·4	4·9	3·6	..	..	..	
	11·3	8·9	8·4	..	..	..	
	10·5	7·8	6·6	..	..	..	
	15·8	8·6	10·0	..	..	..	
	14·0	11·2	9·2	..	..	..	
	14·7	11·5	9·9	..	..	..	
	15·4	12·5	10·7	..	..	..	
	15·6	12·0	9·6	..	..	..	
Bundaberg red volcanic— Lab. No. 2410—							
Normal, air dried	5·8	..	..	..	..	..	
	6·6	..	..	..	..	..	
	6·5	..	..	..	..	..	
	5·4	..	..	..	..	..	
	6·9	..	..	..	..	..	
Dry ground	2·4	..	..	..	..	..	
Remoistened to 20% moisture	8·8	..	..	..	..	..	
Remoistened to 20% moisture, then sieved	4·3	..	..	..	..	..	2 mm. sieve used
Worked at 20% moisture ..	8·7	..	..	..	..	..	
	6·8	..	..	..	..	..	

APPENDIX B—continued.

RELATIVE PERCOLATION RATES—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute. ¼–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	Remarks.
	%	%	%	%	%	%	
Worked at 22% moisture ..	7·8	..	..	..	..	..	
Worked at moisture equivalent	37·3	..	..	..	..	..	Moisture equivalent = 25%
	26·7	..	..	..	..	..	
	34·5	..	..	..	..	..	
	>50	..	..	..	..	..	
	30·0	17·3	15·0	10·2	9·8	..	
	35·0	18·5	11·2	7·0	6·5	..	
Worked at 27% moisture ..	23·3	..	..	..	..	..	
Worked at 30% moisture ..	11·7	..	..	..	..	..	
Worked at 35% moisture ..	2·9	..	..	..	..	..	
Worked at 38% moisture ..	2·0	..	..	..	..	..	
Worked at 40% moisture ..	2·1	..	..	..	..	..	
Worked at moisture equivalent, then air dried	8·0	..	..	..	..	..	
	8·4	..	..	..	..	..	
Lab. No. 6355—							
	6·9	..	..	..	..	..	Cultivated for cane for 40 years. (Cf. 6354, virgin phase of this soil)
	9·1	..	..	..	..	..	
Normal, air dried	7·4	..	..	..	..	..	
	6·3	5·5	4·2	..	..	..	
	6·8	4·8	4·1	3·3	..	..	
Crushed lumps	3·8	2·9	3·1	2·2	..	..	
Dry ground	2·4	2·1	1·8	1·7	..	..	
	2·8	2·4	2·2	2·0	..	..	
	38·7	22·8	13·5	9·2	8·2	..	
Worked at moisture equivalent	37·5	24·7	22·5	15·5	15·8	..	
	30·2	23·3	19·7	..	..	..	
	16·2	10·8	10·1	8·3	9·0		
	12·0	8·5	8·2	6·8	6·4	..	
Worked at moisture equivalent, then air dried	11·8	8·6	8·6	7·8	8·9	..	
	14·4	11·8	10·7	..	..	..	
	16·9	14·3	12·1	..	..	..	
Lab. No. 6354—							Virgin soil :
	27·7	20·8	..	..	..	..	Not passed through sieve
Normal, air dried	22·9	18·1	15·7	14·5	..	..	
	23·8	21·5	22·0	19·3	..	..	Passed through 2 mm. sieve
	57·7	52·0	..	..	..	..	
Crushed lumps	2·4	1·7	1·8	1·5	1·6	..	
	2·3	1·6	1·6	1·3	1·3	..	
	27·2	18·0	31·8	11·3	11·0		Moisture equivalent = 31·5%
	48·7	32·0	26·3	16·3	17·1		
Worked at moisture equivalent	23·3	14·7	12·4	9·5	8·2	6·9	
	51·3	31·0	24·1	16·6	11·3	8·3	
	47·6	33·3	25·8	..	..	..	
	26·8	21·0	18·8	..	..	..	
Worked at moisture equivalent, then air dried	114·0	92·0	..	..	..	..	
	97·0	72·0	..	..	..	..	

APPENDIX B—continued.

RELATIVE PERCOLATION RATES—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute.						Remarks.
	½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	
Cairns red schist— Lab. No. 6351—							
Normal, air dried	9·8	6·7	6·4	6·7			
	9·5	6·8	7·0	7·6			
	9·3	6·9	7·0	7·6			
	8·8	6·2	6·9	7·4			
	10·2	8·4	8·4	7·3	8·0	6·3	
	11·6	9·2	8·8	7·9	7·5	6·2	
Dry ground	6·3	6·0	5·6	..	..	..	
Worked at moisture equivalent	14·1	10·3	9·3	10·4			
	10·9	6·2	4·8	4·8			
	15·8	11·7	9·9	8·3	..	..	
Worked at moisture equivalent, then air dried	6·1	3·7	3·1	..	..	..	
	9·3	7·7	8·4	7·4	7·9	..	
	8·9	7·1	7·4	7·3	6·4	..	
Worked at sticky point ..	17·2	13·2	10·4	8·5	..	..	Dried partially and remoistened to optimum moisture
	11·9	10·7	9·8	9·5	..	..	

COMMENTS.

Working at the moisture equivalent produced an increase in the percolation rate for all soil types except the Burdekin alluvial. In the case of the two Bundaberg soils this increase was remarkable; but the red volcanic soil was the only one to retain a greatly augmented rate after final air drying.

The Burdekin alluvial appeared to be improved by wetting and drying and by cropping to beans.

The percolation rate of all soils was decreased by dry grinding.

APPENDIX C.

Hardness Data.

Soil and Treatment.	Hardness Readings.	Mean Value.	Remarks.
Burdekin alluvial—			
Lab. No. 4825—			
In original lumpy condition	..	1	
Lumps crushed	3·9*; 4·2	..	*Sample not centrifuged
Dry ground	..	4·0	
Cropped to beans—			
Pot No. 1. Normal, air dried	1·0; 1·5	1·2	
Pot No. 1. Dry ground	5*; 8	..	*Sample not centrifuged
Pot No. 1. Worked at moisture equivalent	..	8·0	
Pot No. 1. Pressed heavily at 24% moisture	..	20·8	
Pot No. 1. Worked at sticky point	..	28·5	
Dry ground; cropped to beans—			
Pot No. 2. Normal	..	2·0	
Pot No. 2. Dry ground	9*; 15·0; 17·4	..	*Sample not centrifuged
Pot No. 2. Pressed heavily at 24% moisture	..	20·6	
Partially sodium-saturated—			
Soil E (8·3% Na). Normal, air dried	7*; 15	..	*Sample not centrifuged
Soil D (16·5% Na)	17*	..	*Sample not centrifuged
Soil A (16·8% Na)	20*; 24	..	*Sample not centrifuged
Soil B2 (21·4% Na)	Almost impenetrable	..	
Partially sodium-saturated, then mishandled—			
Soil E. Dry ground	..	17·8	
Worked at 15% moisture	..	30	
Worked at 20% moisture	..	Imp.	
Soil D. Dry ground	..	25	
Worked at 25% moisture	..	Imp.	
Soil A. Dry ground	..	29	
Worked at 25% moisture	..	Imp.	
Lab. No. 6350—			
Original moist sample	6·7; 7·3; 7·0	7·0	
Normal, air dried	..	4·0	
Re-wetted, centrifuged, then dried	..	4·0	
Re-wetted, then air and oven dried	5·5; 6·5	6·0	
Dry ground	10·2	..	
Worked at optimum moisture (15%)	..	1·5	Pressed lightly
Worked at moisture equivalent	7; 7; 7; 8	7·2	Sub-irrigated, centrifuged, pressed lightly
Pressed heavily at moisture equivalent	..	10·5	Normal, air dry sample
	..	16·3	Original moist sample used
Pressed heavily at sticky point	Impenetrable	..	
Other Burdekin alluvials—			
Lab. No. 1229 (5% Na)—			
Normal, air dried	5·0; 7·2; 5·4; 5·8; 11·4; 14·0; 17·8; 12·7; 13·6; 11·8	5·8* / 13·6	*Sample not centrifuged
Dry ground	..	24·4* / 25·7	* Sample not centrifuged
Remoistened only to optimum moisture	..	3·9	Sample not centrifuged
Worked at optimum moisture	Just penetrable	..	

APPENDIX C—continued.

HARDNESS DATA—*continued.*

Soil and Treatment.	Hardness Readings.	Mean Value.	Remarks.
Other Burdekin alluvials—*continued.*			
Lab. No. 4205 (10% Na)—			
Normal, air dried		4·0*	*Sample not centrifuged
		10·5	
Pressed heavily at moisture equivalent		24·1	
Lab. No. 4824 (21% Na)—			
Normal, air dried	25·0; 17·6; 22·3; 18·4; 18·0	20·3	
Remoistened only to optimum moisture		18·4	
Dry ground		30	
Worked at optimum moisture	Just penetrable		
Russell River alluvial—			
Lab. No. 2412—			
Normal, air dried	1; 2	1·5	
Dry ground	4·0; 1·5; 3·9	3·1	
Worked at moisture equivalent		5·0	Sub-irrigated and centrifuged
Worked at sticky point		4·8	Pressed lightly
		14·0	Sub-irrigated and centrifuged
Partially sodium-saturated (18%)		1·0	
Cropped to beans in pot experiment	3; 1·5; 1·5; 1·5	1·9	
Lab. No. 6352—			
Normal, air dried		1·1	
Dry ground	11·0; 4·0; 6·9	7·3	
Pressed lightly at moisture equivalent		2·0	Moisture equivalent = 28·6%
Pressed heavily at moisture equivalent	3·0; 4·2	3·6	
Worked at moisture equivalent		4·0	Sub-irrigated, centrifuged, pressed lightly
Pressed heavily at 36% moisture		16·1	
Worked at sticky point		12·5	Pressed lightly
Bundaberg red forest—			
Lab. No. 2411—			
Normal, air dried		< 1	
Dry ground	1·0; 4·0; 3·2	2·7	
Worked at moisture equivalent		4·5	Sub-irrigated and centrifuged
Worked at sticky point		7·0	Pressed lightly
		18·0	Sub-irrigated and centrifuged
Partially sodium-saturated (15%)		< 1	
Cropped to beans in pot experiment	1·5; 1; 1; 1	1·1	
Lab. No. 6353—			
Normal, air dried		< 1	Not centrifuged
		< 1	Centrifuged
Dry ground		3·0	
Worked at moisture equivalent		1·9	Centrifuged and pressed lightly
		4·8	Pressed heavily
Pressed heavily at 14% moisture		4·6	
Worked at sticky point	5·8; 7·8	6·8	Pressed lightly

APPENDIX C—continued.

HARDNESS DATA—*continued.*

Soil and Treatment.	Hardness Readings.	Mean Value.	Remarks.
Bundaberg red volcanic—			
Lab. No. 2410—			
Normal, air dried		< 1	
Dry ground		5·6	
Worked at moisture equivalent		1	Pressed lightly
		1	Sub-irrigated and drained
		3·2	Sub-irrigated and centrifuged
Lab. No. 6355—			
Normal, air dried		< 1	Sub-irrigated and drained
		2·8	Sub-irrigated and centrifuged
Dry ground	10·8	..	
Worked at moisture equivalent		< 1	Pressed lightly
		1·5	Centrifuged and pressed lightly
		2·0	Sub-irrigated and drained
		4·6	Sub-irrigated and centrifuged
Pressed heavily at moisture equivalent		5·7	Moisture equivalent = 27·1%
Pressed heavily at 30% moisture	9·1; 9·3	9·2	
Worked at sticky point		8·2	Pressed lightly. Sticky point 38%
Lab. No. 6354—			
Normal, air dried		< 1	Virgin soil
		3·4	Sub-irrigated and centrifuged
Crushed gently and sieved	4·6; 4·8	4·7	
Dry ground	9·0	..	
Pressed heavily at moisture equivalent	6·7; 8·8	7·8	Moisture equivalent = 31·5%
Worked at sticky point	6·0; 7·0	6·5	Pressed lightly. Sticky point = 54%
Cairns red schist—			
Lab. No. 6351—			
Normal, air dried		1·0	
Dry ground	6·1; 3·0	..	
Worked at moisture equivalent		3·4	Pressed lightly
Pressed lightly at moisture equivalent		1·0	Moisture equivalent = 15·2%
Pressed heavily at moisture equivalent	2·4; 6·5	..	
Pressed heavily at 28% moisture		21·7	
Worked at sticky point	19·0; 22·5	..	Pressed lightly. Sticky point = 35%

APPENDIX D.

$$\text{Percentage Dispersion} = \frac{\text{(Silt + Clay) in sample}}{\text{(Silt + Clay) at complete dispersion.}} \times 100$$

Soil and Treatment.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Percentage Dispersion.	Remarks.
	%	%	%	%	%	
Burdekin alluvial—						
Lab. No. 4825—						
Completely dispersed	13·9	40·6	20·9	24·6	100·0	
Normal, air dried	14·7	67·0	16·9	1·4	40·2	
Dry ground	17·5	63·5	16·7	2·3	41·8	
Worked at optimum	29·8	53·9	13·8	2·5	35·8	Optimum moisture = 15%
Worked at moisture equivalent	16·8	62·0	19·1	2·1	46·6	Moisture equivalent = 22·5%
Worked at moisture equivalent, then dry ground	18·1	54·0	24·6	3·3	61·3	
Worked at sticky point ..	15·6	50·8	26·1	7·5	73·8	Sticky point = 30%
Cropped to beans	23·1	63·6	12·3	1·0	29·2	
Partially sodium-saturated—						
Soil E (8·3% Na)	16·8	62·7	18·6	1·9	45·1	
Soil D (16·5% Na)	14·6	52·7	27·1	5·6	71·9	
Soil A (16·8% Na)	15·7	55·9	25·0	3·4	62·4	
Soil B2 (21·4% Na)	13·2	46·3	28·0	12·5	89·0	
Soil F (84·9% Na)	14·2	44·2	22·9	18·7	91·4	
Partially sodium-saturated, then mishandled—						
Soil D. Dry ground. Worked at 33% moisture	11·7	52·8	29·0	6·5	78·0	
	13·2	42·4	25·8	18·6	97·6	
Soil A. Dry ground. Worked at 30% moisture	11·3	51·8	29·4	7·5	81·1	
	12·5	42·0	24·2	21·3	100·0	
Soil E. Worked at 15% moisture	17·1	60·0	19·4	3·5	50·3	
Lab. No. 6350—						
Completely dispersed	2·6	54·0	19·7	23·7	100·0	
Normal, air dried	12·1	70·8	15·6	1·5	39·4	
Dry ground	7·9	72·0	18·0	2·1	46·2	
Original moist sample	15·9	63·2	17·3	3·6	48·1	
Worked at moisture equivalent	6·5	75·6	15·7	2·2	41·2	Moisture equivalent = 21·4%
Worked at moisture equivalent, then dry ground	5·9	71·6	20·3	2·2	51·8	
Dry ground, then worked at moisture equivalent	5·7	71·6	19·6	3·1	52·2	
Other Burdekin alluvials—						
Lab. No. 1220—						
Completely dispersed	4·2	23·1	41·2	31·5	100·0	
Normal, air dried	12·7	67·9	17·3	2·1	26·7	
Lab. No. 1221—						
Completely dispersed	9·6	26·8	31·0	32·6	100·0	
Normal, air dried	16·7	65·9	15·3	2·1	27·4	
Lab. No. 1222—						
Completely dispersed	8·6	38·0	34·9	18·5	100·0	
Normal, air dried	10·3	74·5	13·3	1·9	28·5	
Lab. No. 1223—						
Completely dispersed	28·7	39·0	5·0	27·3	100·0	
Normal, air dried	20·6	67·8	10·4	1·2	35·9	

APPENDIX D—continued.

PERCENTAGE DISPERSION = $\frac{\text{(Silt + Clay) in sample}}{\text{(Silt + Clay) at Complete Dispersion}} \times 100$—*continued.*

Soil and Treatment.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Percentage Dispersion.	Remarks.
	%	%	%	%	%	
Lab. No. 1224—						
Completely dispersed	1·9	46·3	24·8	27·0	100·0	
Normal, air dried	3·5	80·0	13·8	2·7	31·9	
Lab. No. 1225—						
Completely dispersed	8·6	55·7	15·6	20·1	100·0	
Normal, air dried	4·3	83·8	10·5	1·4	20·1	
Lab. No. 6331 (Clod Sample)—						
Clods completely dispersed	5·2	33·1	29·9	31·8	100·0	
Clods slaked	28·0	50·1	19·5	2·4	35·5	
Clods crushed	4·2	57·4	32·2	6·2	62·2	
Russell River alluvial—						
Lab. No. 2412—						
Completely dispersed	8·0	37·6	23·9	30·5	100·0	
Normal, air dried	8·0	76·6	14·3	1·1	28·3	
Dry ground	9·4	71·5	16·9	2·2	35·1	
Dry ground, then worked at sticky point	5·1	69·5	22·2	3·2	46·7	Sticky point = 43%
Worked at sticky point, then dry ground	6·2	63·9	24·8	5·1	55·0	
Cropped to beans	19·8	67·7	11·7	0·8	23·0	
Partially sodium-saturated (18% Na)	8·1	68·2	20·8	2·9	43·6	
Lab. No. 6352—						
Completely dispersed	10·1	20·5	31·1	38·3	100·0	
Normal, air dried	30·9	54·8	12·7	1·6	20·6	
Worked at sticky point	38·8	33·3	22·9	5·0	40·2	Sticky point = 52%
Bundaberg red forest—						
Lab. No. 2411—						
Completely dispersed	31·6	24·2	14·1	30·1	100·0	
Normal, air dried	39·1	51·1	8·6	1·2	22·2	
Dry ground	36·8	49·3	12·1	1·8	31·4	
Dry ground, then worked at sticky point	37·5	55·8	5·9	0·8	15·2	Sticky point = 21%
Worked at sticky point, then dry ground	35·2	46·7	15·6	2·5	40·9	
Cropped to beans	44·4	50·1	5·1	0·4	12·4	
Partially sodium-saturated (15% Na)	38·5	47·9	12·2	1·4	30·8	
Lab. No. 6353—						
Completely dispersed	46·4	23·8	6·2	23·6	100·0	
Normal, air dried	57·0	38·6	3·9	0·5	14·8	
Worked at sticky point	54·3	32·4	10·6	2·7	44·6	Sticky point = 23%
Bundaberg red volcanic—						
Lab. No. 2410—						
Completely dispersed	14·6	10·2	15·7	59·5	100·0	
Normal, air dried	58·1	34·6	5·9	1·4	9·7	
Dry ground	43·3	40·6	13·6	2·5	21·4	
Worked at moisture equivalent	64·9	23·6	7·4	4·1	15·3	Moisture equivalent = 25%
Dry ground, then worked at sticky point	31·8	58·8	8·4	1·0	12·5	Sticky point = 35%
Worked at sticky point, then dry ground	30·7	45·9	20·5	2·9	31·1	

APPENDIX D—continued.

PERCENTAGE DISPERSION = $\frac{\text{(Silt + Clay) in sample}}{\text{(Silt + Clay) at complete dispersion}} \times 100$—*continued.*

Soil and Treatment.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Percentage Dispersion.	Remarks.
	%	%	%	%	%	
Lab. No. 6355—						Cultivated for cane for 40 years.
Completely dispersed	12·8	8·6	18·4	60·2	100·0	(Cf. No. 6354, virgin phase
Normal, air dried	48·8	45·3	4·7	1·2	7·5	of same soil)
Worked at moisture equivalent	57·9	30·9	7·2	4·0	14·2	Moisture equivalent = 27%
Lab. No. 6354—						
Completely dispersed	22·6	9·5	23·8	44·1	100·0	Virgin soil
Normal, air dried	72·3	22·0	4·5	1·2	8·4	
Cairns red schist—						
Lab. No. 6351—						
Completely dispersed	7·7	50·5	16·4	25·4	100·0	
Normal, air dried	17·0	77·6	5·1	0·3	12·9	
Worked at moisture equivalent	18·5	72·9	7·9	0·7	20·6	Moisture equivalent = 15·2%
Worked at sticky point ..	11·5	83·5	4·6	0·4	12·0	Sticky point = 35%
Dry ground	15·0	78·1	6·6	0·3	16·5	

COMMENTS.

Burdekin alluvial.

Neither dry grinding nor working at the moisture equivalent caused a very great increase in the dispersion. These treatments, applied successively, gave a cumulative result which was the same regardless of the order in which the treatments were given.

Wet working at the sticky point caused a much increased dispersion.

Partial sodium-saturation caused a large increase in dispersion and when this was followed by dry grinding or wet working the results appeared more than additive. A 15 per cent. sodium-saturation followed by working at the sticky point was sufficient to cause complete dispersion.

The original moist field sample was improved by air drying; and cropping to beans was the only treatment which showed an improvement above the normal air dry condition. Other Burdekin samples varied in normal dispersion from 20 per cent. to 35 per cent. Hard clods slaked down to a normal value but if crushed they retained a high dispersion.

Russell River alluvial.

Dry grinding increased the dispersion, as also did partial sodium-saturation. Dry grinding followed by working at the sticky point caused a 50 per cent. increase in the dispersion and the same treatment in reverse order was even more effective. Cropping to beans definitely assisted granulation of the particles.

Bundaberg red forest.

Dry grinding and partial sodium-saturation both increased the dispersion. Dry grinding followed by working at the sticky point produced a lower dispersion than the original normal value; but the same treatments in reverse order left a much more dispersed soil. Cropping to beans produced a very definite improvement in the amount of dispersion.

Bundaberg red volcanic.

Dry grinding was very effective in increasing the original (low) value of the dispersion. Whilst dry grinding followed by working at the sticky point produced some increase, the reverse process was particularly effective. Working at the moisture equivalent (= optimum) was also dispersive in its action. Cropping to sugar cane over 40 years had caused no significant increase in the normal dispersion of this soil type.

In soil types of low normal dispersion, working either wet or dry readily produced high proportional increases; and the opposite was true of types with high normal dispersion. Nevertheless, the absolute values attained by the two Bundaberg soils (types with low original values) never exceeded the normal air-dry value of the Burdekin alluvial. Cropping to beans in pots, was, for all types tried, an aggregate-forming treatment.

STUDIES ON THE EFFECTS OF TRANSPORT AND STORAGE ON THE BACTERIOLOGICAL QUALITY OF RAW MILK.

Part 1.—The Reduction of Methylene Blue by Raw Milk as Influenced by Time and Temperature of Storage.

By V. R. SMYTHE, B.Sc.Agr., Assistant Dairy Technologist, Dairy Research Laboratory, Division of Dairying.

TABLE OF CONTENTS.

Page.

Summary 129

Introduction 130

Part 1.—The Reduction of Methylene Blue by Raw Milk as Influenced by Time and Temperature of Storage—

General Considerations 131

Effects of Storage Time and Temperature within the Temperature Range 20 deg. C.–35 deg. C. 132

Experimental Methods 134

Collection of Samples 134

Treatment of Samples 134

Technique of Methylene Blue Reduction Tests 136

Experimental Results 137

Effects of Storage Time 139

Effects of Storage Temperature 142

Interaction of Time and Temperature 143

Correlation of Control Value and Shade Temperature with Time and Temperature Effects 145

Experimental Results 145

Effects of Storage Time and Temperature within the Temperature Range 5 deg. C.–15 deg. C. 148

Experimental Results 148

Discussion 152

Effects of Storage Time 152

Effects of Storage Temperature 153

Interaction of Time and Temperature 154

Relationship between Control Value and Rate of Change in Quality .. 154

Effects of other Factors 155

Bactericidal Property of Fresh Milk 155

References 155

SUMMARY.

Certain aspects of Brisbane's milk supply are discussed and trends of air temperature and raw milk quality are illustrated graphically, using data obtained by testing 95,000 milk samples over a period of three years.

Methylene blue reduction tests were performed on samples of raw milk collected from 20 farms in the Brisbane milk district and incubated for various periods of time up to five hours at temperatures ranging from 5 deg. C. to 35 deg. C.

The criterion adopted for deterioration in milk quality was the fall in reduction time, which is represented by the difference between the reduction time prior to incubation and the reduction time after the application of any given treatment.

The fall in reduction time produced by a rise in temperature from 20 deg. C. to 35 deg. C. was very marked, but was not strictly linear, the steepest fall occurring when the temperature rose from 25 deg. C. to 30 deg. C. Incubation at temperatures below 20 deg. C. caused an increase in the reduction time which was noticeable immediately after the initial storage period of 30 minutes. This evidently results from the sudden lowering in temperature at the commencement of incubation, and the effect appears to be independent of the amount of temperature change.

At most temperatures an increase in storage time up to 5 hours produced marked trends, which appeared to be strictly linear. The exception occurred at 10 deg. C., at which temperature no effect resulting from the period of storage was shown. At 5 deg. C. increase in the duration of storage produced a progressive increase in the reduction time. All temperatures above 10 deg. C. resulted in a marked fall in the reduction time as the storage period increased. Gradients of deterioration have been calculated for all seven temperatures employed.

The interaction of the time factor and the reduction trends due to temperature change was positive, marked and almost linear, as was also the reciprocal action of temperature on the trends resulting from time.

As the storage temperature increased, the rate of deterioration (fall in reduction time) was greater in good quality milks than in milks of inferior quality. Furthermore, this rate of deterioration with temperature increased as storage time was prolonged and such an added deterioration was greater when milk quality was high. No correlation was obtained between the initial quality of a milk and the effect of storage time.

The shade air temperature of the day of sampling was found to exert no influence on the observed trends in the methylene blue reduction time.

INTRODUCTION.

During the three-year period 1942-1944 the raw milk supplied to Brisbane milk depots for the chilled and pasteurized milk trades was subjected to a series of quality tests in accordance with an extensive system of control. The summarized results of 95,000 tests conducted during the testing period, expressed as a percentage of all methylene blue reduction times below the 4-hour standard and plotted in Figure 1, show that a marked deterioration of quality occurs

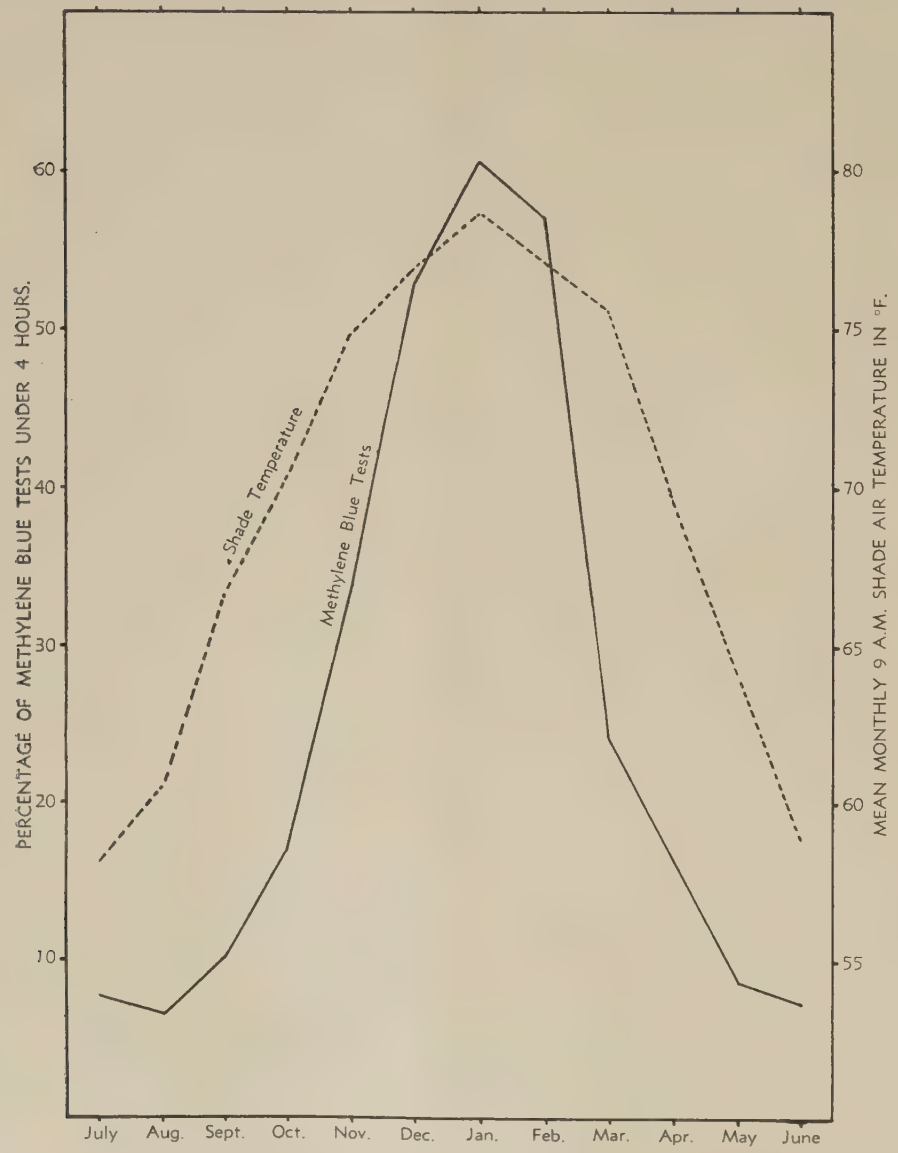


Figure 1.

Showing trends in shade temperature and raw milk quality for the period 1942-1944.

during the summer months. The pronounced rise in the percentage of low-quality milks from October to January is too great to be explained adequately in terms of increased farm contamination such as might take place as a result of increased bacterial development on improperly cleansed and imperfectly sterilized utensils at the higher temperatures prevailing. The most probable explanation of the variation in milk quality is that a considerable temperature effect operates during transport and storage of the milk following its production. This is supported by the manner in which the line representing milk quality in Figure 1 follows that representing the mean shade air temperature at 9 a.m., at which time of the day the greater part of the milk supply is in transit.

While the seasonal effect demonstrated was expected and was considered to be attributable largely to air temperature or to some factor closely dependent on this, it was obvious early in the investigation that various conditions resulting from the war accentuated changes in milk quality. An attempt was therefore made to determine to what extent these factors influence milk quality. The main factors may be stated as time and temperature of transport and time and temperature of storage at the milk depots prior to handling. Transport of raw milk in the area serving Brisbane has never been highly organized nor very efficient, and during the war years increased loads, slower trips, and delays at depots have lowered efficiency further. The increasing demand for fluid milk, and particularly for pasteurized milk, has considerably over-taxed factory equipment: in the case of some milk-pasteurizing plants the quantity of milk received has been doubled without any appreciable change in facilities for handling the supply. This has resulted in a prolonged daily receiving period, during which some milk has of necessity been stored at atmospheric temperature awaiting treatment. Procter (1943, a and b) and Rowlands and Provan, as quoted by Barkworth (1944), have commented on a deterioration of milk quality in Great Britain caused by adverse transport conditions brought about by war.

It is the purpose of this series of papers to present the results of studies on the deterioration in the quality of raw milk which occurs during transit and storage in the Brisbane area, on the effect of the milk container on milk quality, and on the changes in pasteurizability of raw milk brought about by transport and storage conditions.

Part 1.—The Reduction of Methylene Blue by Raw Milk as Influenced by Time and Temperature of Storage.

GENERAL CONSIDERATIONS.

The greater part of the raw milk delivered to Brisbane for pasteurizing and chilling is derived from the morning milking. During the winter and spring months, when production is low, some milk from the evening milking is also drawn upon, but the proportion of evening milk decreases steadily as the production increases in response to the summer rains, with the result that morning

loads become progressively heavier, causing protracted delays in handling and transit. Such delays, occurring as they do during summer, coincide with high air temperatures. Furthermore, these delays mean that milk is held under a steadily increasing air temperature from hour to hour through the summer mornings. The temperature trends for each of the seasons of the year are shown in Figure 2, which has been prepared from the mean-hourly-shade-air-temperatures recorded for Brisbane for the months July, 1943, to June, 1944.

Not all milk supplies are cooled before leaving the farms, and where coolers are in use the cooling process consists merely of removing the body heat by means of water which is itself at or only slightly below atmospheric temperature. It appears from observations made that without refrigeration milk temperatures below 70 deg. F. cannot be reached during summer months. Since refrigerated transport is as yet unavailable there exists no protection for the milk against the effect of high temperatures, and during the summer months it is exceedingly common for milks to exhibit a temperature between 80 deg. F. and 90 deg. F. on arrival at the depots.

There is some evidence that the milk grading system in operation at present has been attended by considerable unfairness to milk producers. Milking is completed on practically all farms between the hours of 6 a.m. and 8 a.m., but the arrival times at depots are staggered to facilitate handling. This procedure means, in effect, that producers whose milk is handled at the depots by 9 a.m. usually obtain a satisfactory methylene blue reduction time for their article much more readily than producers whose milk is sampled several hours later. It is intended to use the information obtained in this experimental work as an aid in evolving a system of milk quality control which will obviate unfairness.

The data presented here were obtained from a study of the effects of time and temperature of storage on the methylene blue reduction time of fresh raw milk. Most attention has been paid to storage temperatures from 20 deg. C. (68 deg. F.) to 35 deg. C. (95 deg. F.) and results obtained over this temperature range have been treated separately from results obtained at lower temperatures. This has been considered desirable in view of the fact that milk quality suffers most during summer, when high temperatures of transport and storage prevail.

EFFECTS OF STORAGE TIME AND TEMPERATURE WITHIN THE TEMPERATURE RANGE 20 DEG. C.–35 DEG. C.

Some work has been published overseas showing the effect of moderate temperatures on the reduction time of raw milk, but the information is far from being complete. Newton (1942) observed the reduction time of raw milk to deteriorate markedly during summer months and particularly during long periods of transport, but no details of temperature are given. Nichols and Edwards (1936) found that an increase in temperature of 4 deg. F., within

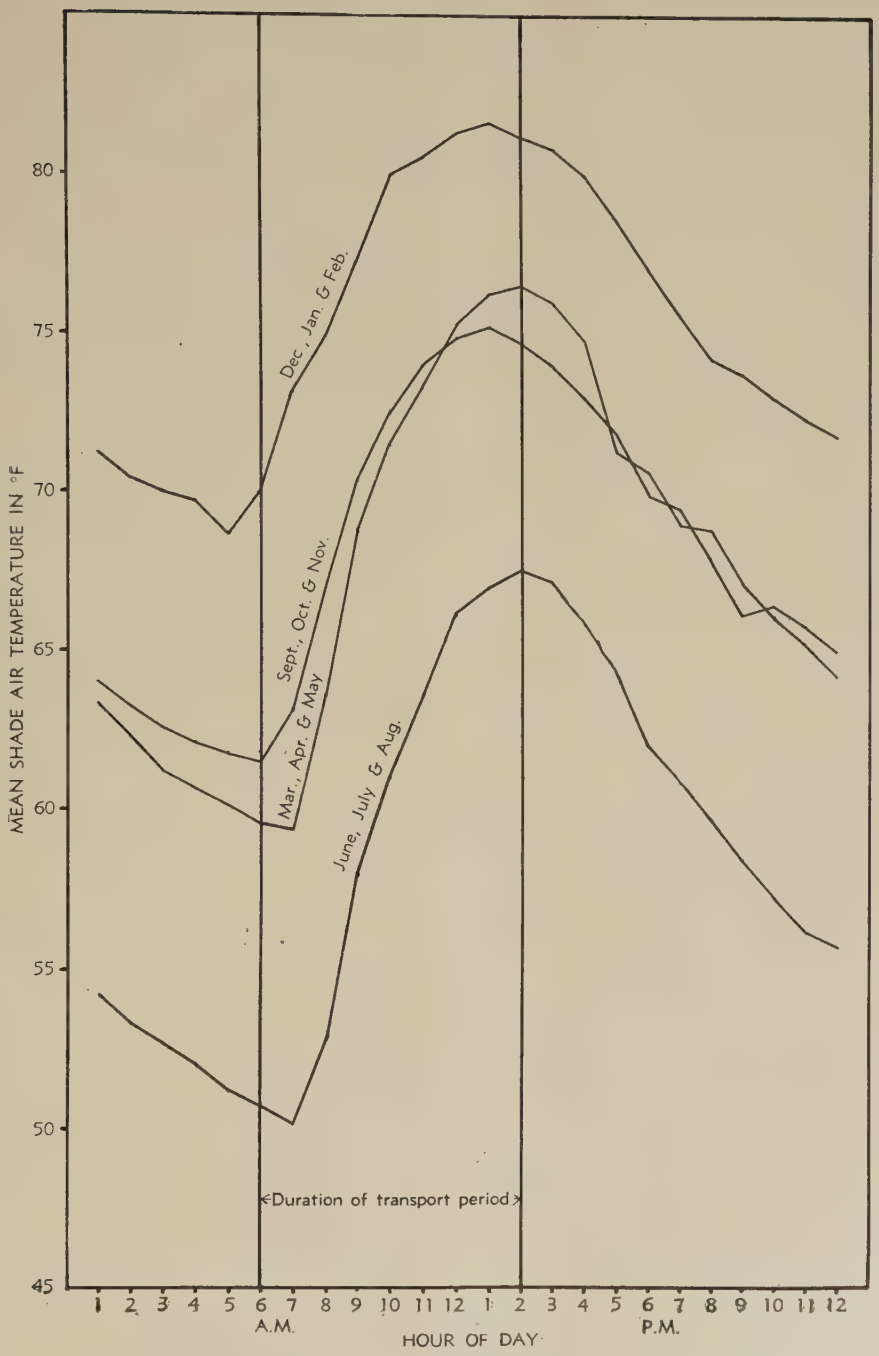


Figure 2.

Showing mean shade air temperatures at Brisbane from July, 1943, to June, 1944.

the temperature range 40 deg. F—68 deg. F., lowered the average reduction time by 70 minutes. These workers based their results on temperatures at the time of testing, which were taken as reflecting the storage temperature. Hoy and Braz (1938) concluded as a result of their work that a storage time of 18 hours at 70 deg. F. constituted drastic treatment of raw milk samples, causing reduction times of less than 4½ hours for milks considered to be of satisfactory initial quality.

Experimental Methods.

The greater part of the experimental work was done during November, 1943, December, 1943, and January, 1944, but several additional experimental samples were taken during October, 1944. Shade temperature records for the days on which tests were conducted showed that the mean daily temperature varied from 64 deg. F. to 76 deg. F.

Separate samples from 20 different farms were taken for the experimental work, and milk from the morning milking was used exclusively, as this permitted the greater portion of the work to be conducted during daylight hours. Farms were chosen at random without any warning being given that a sample was to be taken. In this way it was hoped to obtain a true sample by preventing farmers altering their normal methods of production. The samples included milks produced and treated by various methods as detailed in Table 1. Some milks were produced while the cows were being fed in stalls. The standard of hygiene on these producing farms varied considerably; in Table 1 it is given for convenience as "poor," "fair", or "good."

Because of the large number of tests and incubations which had to be performed in a limited period, it was impracticable to draw samples from more than two experimental farms on any one day.

Collection of Samples.

The producing farms were visited for the collection of samples and care was taken to secure samples as soon as practicable following the completion of milking. All the milk drawn during the milking was sampled into sterilized containers from the cans in which the milk was normally conveyed to the depot. In each case the composite sample thus obtained—approximately 1 litre—contained milk from both first- and last-milked cows in the herd. Since it was the aim to treat the milk from each farm as a separate replication unit in the experiment, while still preserving normal conditions as far as possible, this age discrepancy, which did not exceed two hours, had to be overlooked.

Treatment of Samples.

An effort was made to keep the interval between milking and commencement of laboratory tests as short and as constant as possible. This period actually varied between one and three-quarters and two and one-quarter hours (see Table 1), during which time the milk was kept under atmospheric conditions.

Icing of samples was purposely avoided, the reasons being (*a*), the desirability of keeping the samples as near as possible to normal commercial conditions, and (*b*), the uncertainty of the effect of icing on the subsequent behaviour of a sample.

The temperature of each milk sample was taken in cans at the farm and again on arrival at the laboratory; the figures are shown in Table 1.

In order to provide information concerning the quality of the experimental milk from each farm additional to that given by the methylene blue reduction tests, plate counts were performed on all farm samples before and after laboratory pasteurization. All plates were made on the tryptone-glucose-extract-milk-agar recommended by the American Public Health Association (1941), with incubation at 37 deg. C. for 48 hours. Laboratory pasteurization was at 63 deg. C. for 30 minutes, followed by immediate shock cooling in an ice and water mix. The results of the plate counts appear in Table 1.

Table 1.

Relevant Date concerning Experimental Samples.

Sample No.	Records of Farm Observations.	Milk Temperature °C.		Period from Milking to Testing.	Methylene Blue Reduction Time (Control value). Hours.	Plate Count per ml. at commencement of methylene blue control test.	
		Milk in Cans at Farm.	Milk Sample at Laboratory.			Raw milk.	After Lab. Pasteurization 63°C. for 30 min.
1	Hand milked, uncooled, hygiene fair	33·5	24	2 hr. 15 min.	5¾	10,000	500
2	Hand milked, cooled, hygiene poor	28	25	2 hr.	4½	110,000	7,000
3	Hand milked, uncooled, hygiene poor	34	26	2 hr.	5	58,000	430
4	Machine milked, uncooled, hygiene fair	33	26	2 hr. 15 min.	4½	..	..
5	Hand milked, uncooled, hygiene poor	33	27·5	2 hr. 15 min.	3¾	160,000	7,000
6	Hand milked, uncooled, hygiene good	34	27	2 hr. 5 min.	6¼	60,000	50
7	Hand milked, cooled, hygiene fair	29	26	1 hr. 50 min.	5¼	140,000	200
8	Hand milked, cooled, hygiene poor	27	26	2 hr.	4⅞	82,000	1,000
9	Hand milked, cooled, hygiene poor	30	27	2 hr. 15 min.	4½	43,000	2,000
10	Hand milked, uncooled, hygiene poor	34	27	1 hr. 45 min.	4½	59,000	1,200
11	Hand milked, uncooled, hygiene poor	36	32	2 hr.	4½	14,000	500
12	Hand milked, cooled, hygiene good	30	29	1 hr. 45 min.	5	9,000	800
13	Hand milked, uncooled, hygiene poor	34	31	2 hr. 15 min.	3½	84,000	900
14	Hand milked, uncooled, hygiene good	34·5	29	1 hr. 45 min.	6¼	30,000	200
15	Machine milked, cooled, hygiene fair	24	25	1 hr. 55 min.	4¾	17,000	130
16	Hand milked, cooled, hygiene good	24	27	1 hr. 45 min.	6¾	10,000	100
17	Hand milked, uncooled, hygiene fair	33	29	2 hr.	5½	8,000	500
18	Hand milked, cooled, hygiene good	29	24	1 hr. 45 min.	7¼	4,000	100
19	Hand milked, cooled, hygiene good	25	23	2 hr.	6½	12,500	2,000
20	Hand milked, cooled, hygiene good	28	27	2 hr. 15 min.	6½	8,000	50

Technique of Methylene Blue Reduction Tests.

Immediately on arrival at the laboratory samples were pipetted in 10 ml. portions into sterile tubes fitted with rubber stoppers. For each milk, two such tubes were at once subjected to the modified methylene blue reduction test described by Wilson (1935), and thus served as controls, each in duplicate. The reduction time of these sub-samples is referred to subsequently as the control value (see Table 1). Twenty more tubes were incubated at each of the temperatures 20 deg. C., 25 deg. C., 30 deg. C., and 35 deg. C. for regular periods of time (half-hourly intervals) up to five hours. Water baths operating within $\pm$ 0·5 deg. C. of the desired temperature were used to obtain even temperature control. Thus incubations were performed in closed tubes without agitation during the incubation period. At half-hourly intervals duplicate tubes of milk were removed from each temperature class and also subjected to the modified methylene blue test. The methylene blue tubes were observed at 15-minute intervals and inverted at half-hourly intervals during the progress of the test.

Great care was found necessary in the reading of the methylene blue tests when tests continued past the daylight hours through twilight and into artificial light. In each such case the tube of milk appeared to hold a faint trace of blue colour. The correct end-point could be determined only by comparing the test with an obviously blue tube on one hand and with a tube long since decolourized on the other.

The experimental design, in addition to giving a control value, gave results for each milk after 40 sets of conditions of time and temperature. As each milk was regarded as a separate unit there were thus 20 replications.

Experimental Results.

The reduction times of duplicate sub-samples differed in 6·6 per cent. of cases, but in only 0·3 per cent. of cases was the difference more than 15 minutes. In every instance of variation the mean was taken as the true value. Table 2 shows the reduction times of the sub-samples of sample No. 9, which is typical in its uniformity of all 20 samples.

For the purposes of the analysis and the interpretation of results the deterioration in quality suffered by a sample of milk under a particular treatment is taken as the criterion of the effect of that treatment. This deterioration is given directly by the value of the fall in reduction time (f), which is the difference between the control reduction time and the reduction time after treatment. The value is usually positive, and is expressed in the tables in eighths of an hour. The choice of the fall in reduction time was quite arbitrary. The ultimate reduction time after treatment could probably have been used to express effects qually well, but most trends would then have been negative. Storage time (t)

Table 2.

REDUCTION TIMES OBTAINED WITH SAMPLE No. 9.

Storage Temp. °C.	Storage Period in Hours.									
	½	1	1½	2	2½	3	3½	4	4½	5
20 ..	5	4¾	4½	4½	4¼	4	3¾	3½	3½	3¼
	5	4¾	4½	4½	4¼	4	3¾	3½	3½	3¼
25 ..	4½	4½	4¼	4	3¾	3½	3¼	2¾	2½	2
	4½	4½	4¼	4	3¾	3½	3¼	2¾	2¼	2
30 ..	4½	4¼	3¾	3½	3	2½	2¼	1¾	1½	1¼
	4½	4¼	3¾	3½	3	2½	2¼	1¾	1½	1¼
35 ..	4¼	4	3½	3	2½	1¾	1½	1¼	1	½
	4¼	4	3½	3	2½	2	1½	1¼	1	½

Control reduction time : 4½ hours.

is recorded in hours, and temperature (T) in degrees Centigrade. The observed values of f averaged over all samples are set out in Table 3, together with the respective mean values of f for all temperatures and times and regression coefficients or gradients of fall. The trends shown by these means of time and temperature are obvious, but the data have been subjected to statistical analysis to enable an accurate interpretation of the results to be made.

Table 3.

SUMMARY—MEAN VALUES OF f (IN EIGHTHS OF AN HOUR) AND REGRESSION COEFFICIENTS (GRADIENTS).

Storage Temp. °C.	Storage Time (t) in hours.										Means.	Regression Coefficients.
	½	1	1½	2	2½	3	3½	4	4½	5		
20 ..	−0·2	−0·1	1·2	2·6	3·1	4·7	6·0	7·2	7·9	9·0	4·14	1·099
25 ..	0·8	2·0	3·4	4·7	7·1	8·6	10·2	12·3	14·5	16·7	8·02	1·773
30 ..	2·7	5·0	7·5	10·7	13·5	15·8	18·8	21·3	23·5	26·2	14·51	2·650
35 ..	4·2	8·0	11·9	15·2	18·7	21·2	24·5	27·4	29·8	32·4	19·32	3·119
Means ..	1·86	3·71	6·01	8·28	10·60	12·58	14·88	17·04	18·91	21·10	11·50	2·160
Regression Coefficients	1·515	2·725	3·605	4·380	5·320	5·710	6·410	6·945	7·455	7·980	5·204	0·694

Mean values of f may be converted to hours by multiplying by 0·125.

It will be seen from the analysis of variance (Table 4) that the major portions of the variations between time and temperature means are accounted for by the linear components. Thus the greater part of the effect of time and temperature is linear. Consequently in this analysis most attention is paid to these linear trends. As there are marked variations in the components of error the three items corresponding to the main linear effects are shown separately. In calculating the standard errors of regression coefficients the separate errors have been used. The components of error shown as "remainder" are homogeneous.

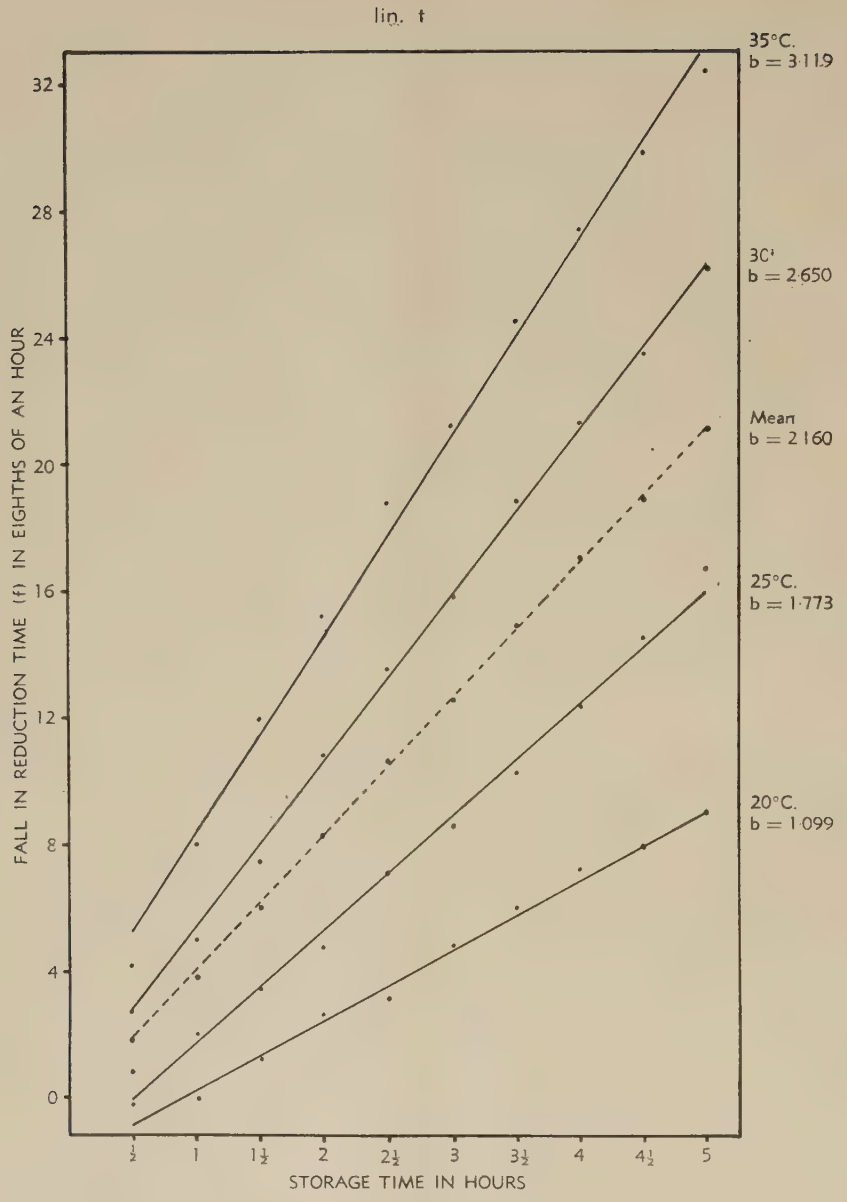


Figure 3.

Showing the effect of increased storage time on the fall in reduction time (f) at four temperatures.

Table 4.

ANALYSIS OF VARIANCE—FALL IN REDUCTION TIME.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Suppliers	19	3,078·114	162·006
Times (t)			
lin. t	1	30,799·440	30,799·440
dev. t	8	13·761	1·720
	9	30,813·201	3,423·689
Temperature (T)			
lin. T	1	27,086·820	27,086·820
dev. T	2	226·394	113·197
	3	27,313·214	9,104·405
Times x Temperatures			
lin. t x lin. T	1	3,971·068	3,971·068
lin. t x dev. T	2	47·916	23·958
dev. t x lin. T	8	80·744	10·093
dev. t x dev. T	16	57·996	3·625
	27	4,157·724	153·990
Error Components			
Suppliers x lin. t	19	818·712	43·090
Suppliers x lin. T	19	1,113·085	58·583
Suppliers x lin. t x lin. T	19	558·744	29·408
Remainder	684	1,539·196	2·250
Total	799	69,391·989	

The terms lin. t, lin. T, and lin. t $\times$ lin. T are all very highly significant and these terms account for the major portions of the variations between the time and temperature means. Dev. T, lin. t $\times$ dev. T, and dev. t $\times$ lin. T are also very highly significant, indicating that the linear specification, especially as regards storage temperature, is not completely adequate. This is shown clearly in Figures 4, 5 and 6.

Effects of Storage Time.

At all four temperatures there is a very marked increase in the value of f as the storage time increases (Figure 3). Linear relations between f and t were estimated for each temperature in the form

$$f - \overline{f}_T = 2\ b_T\ (t - 2{\cdot}75),$$

where $\overline{f}_T$ is the mean value of f for the particular temperature, and t is the storage time in hours. The quantity b_T is the regression coefficient; it measures

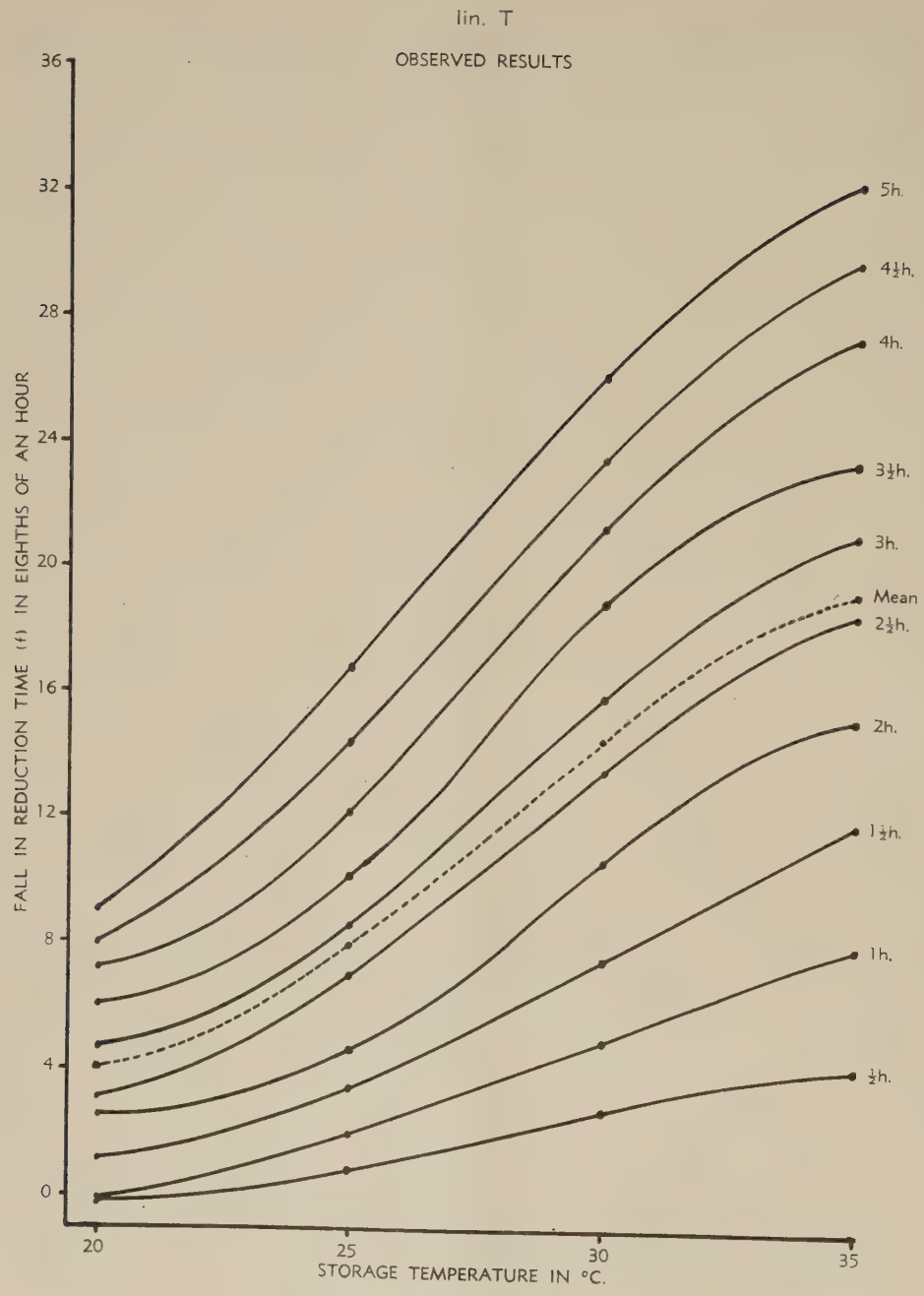


Figure 4a.

Showing the effect of storage temperature on the fall in reduction time (f).

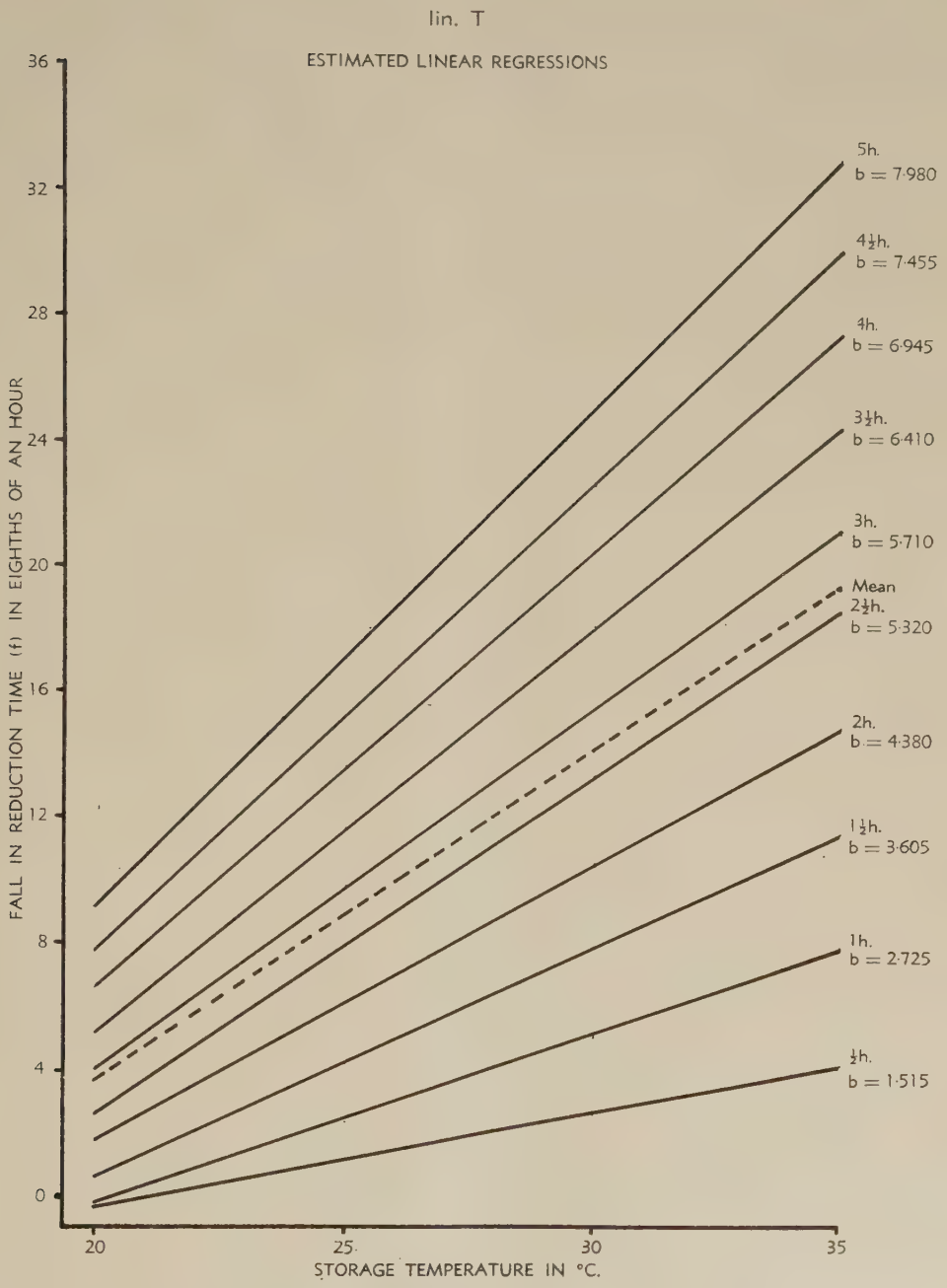


Figure 4b.

Showing the effect of storage temperature on the fall in reduction time (f).

the gradient of f on storage time for the particular temperature and represents the average change in f for each additional half-hour of storage time. The equations for the four temperatures and the mean over all temperatures are

$$\begin{aligned}
&20°C., \quad f - 4{\cdot}14 = 2 \times 1{\cdot}099\ (t - 2{\cdot}75)\ ;\\
&25°C., \quad f - 8{\cdot}02 = 2 \times 1{\cdot}773\ (t - 2{\cdot}75)\ ;\\
&30°C., \quad f - 14{\cdot}51 = 2 \times 2{\cdot}650\ (t - 2{\cdot}75)\ ;\\
&35°C., \quad f - 19{\cdot}32 = 2 \times 3{\cdot}119\ (t - 2{\cdot}75)\ ;\\
&\text{Mean}, \quad f - 11{\cdot}50 = 2 \times 2{\cdot}160\ (t - 2{\cdot}75)\ ;
\end{aligned}$$

The s.e. of each b_T is $\pm$ 0·162 and the s.e. of the mean b_T is $\pm$ 0·0808. All regression coefficients differ significantly from zero. The mean values for the various temperatures and the fitted lines are shown in Figure 3.

Effects of Storage Temperature.

For all storage times there is a very marked increase in f as the storage temperature increases (Figure 4). Linear relations between f and T for each storage time were estimated in the form

$$f - \bar{f}_t = b_t \frac{(T - 27{\cdot}5)}{5},$$

where $\bar{f}_t$ is the mean value of f for the particular storage time, and T is the storage temperature in degrees Centigrade. The regression coefficient b_t is the gradient of f on temperature for a particular storage time and represents the average increase in f for each additional change of 5 deg. C. in storage temperature. The equations for the 10 periods and for the mean over all times are

$$\begin{aligned}
&\tfrac{1}{2}\text{ hr.}, \quad f - 1{\cdot}86 = 1{\cdot}515 \frac{(T - 27{\cdot}5)}{5};\\
&1\text{ hr.}, \quad f - 3{\cdot}71 = 2{\cdot}725\ (\quad ,, \quad);\\
&1\tfrac{1}{2}\text{ hr.}, \quad f - 6{\cdot}01 = 3{\cdot}605\ (\quad ,, \quad);\\
&2\text{ hr.}, \quad f - 8{\cdot}28 = 4{\cdot}380\ (\quad ,, \quad);\\
&2\tfrac{1}{2}\text{ hr.}, \quad f - 10{\cdot}60 = 5{\cdot}320\ (\quad ,, \quad);\\
&3\text{ hr.}, \quad f - 12{\cdot}58 = 5{\cdot}710\ (\quad ,, \quad);\\
&3\tfrac{1}{2}\text{ hr.}, \quad f - 14{\cdot}88 = 6{\cdot}410\ (\quad ,, \quad);\\
&4\text{ hr.}, \quad f - 17{\cdot}04 = 6{\cdot}945\ (\quad ,, \quad);\\
&4\tfrac{1}{2}\text{ hr.}, \quad f - 18{\cdot}91 = 7{\cdot}455\ (\quad ,, \quad);\\
&5\text{ hr.}, \quad f - 21{\cdot}10 = 7{\cdot}980\ (\quad ,, \quad);\\
&\text{Mean}, \quad f - 11{\cdot}50 = 5{\cdot}204\ (\quad ,, \quad).
\end{aligned}$$

The s.e. of each b_t is $\pm$ 0·765 and the s.e. of the mean b_t is $\pm$ 0·242. All regression coefficients, except that for $t = \frac{1}{2}$ hour, differ significantly from zero. The mean values for the various times and the fitted lines are shown graphically in Figure 4.

The significance of the deviation term (dev. T) in the analysis of variance (Table 4) shows that the variation of f with temperature is not adequately represented by a straight line. Both the quadratic and the cubic terms are significant. However, since the main effects are linear, there seems ample justification for treating the results in a linear fashion.

Interaction of Time and Temperature.

The mean values of f, representing the mean fall in reduction time averaged over all temperatures, show a progressive increase with storage time which is adequately described by a linear law (see mean line in Figure 3). The gradients on temperature (b_t) also show a progressive increase with time. Figure 5 shows these gradients plotted against time. The calculated linear relation is

$$b - 5{\cdot}204 = 2 \times 0{\cdot}694 \ (t - 2{\cdot}75),$$

indicating that the mean increase in the gradient of f on temperature is $0{\cdot}694 \pm 0{\cdot}0597$ for each half-hour change in storage time.

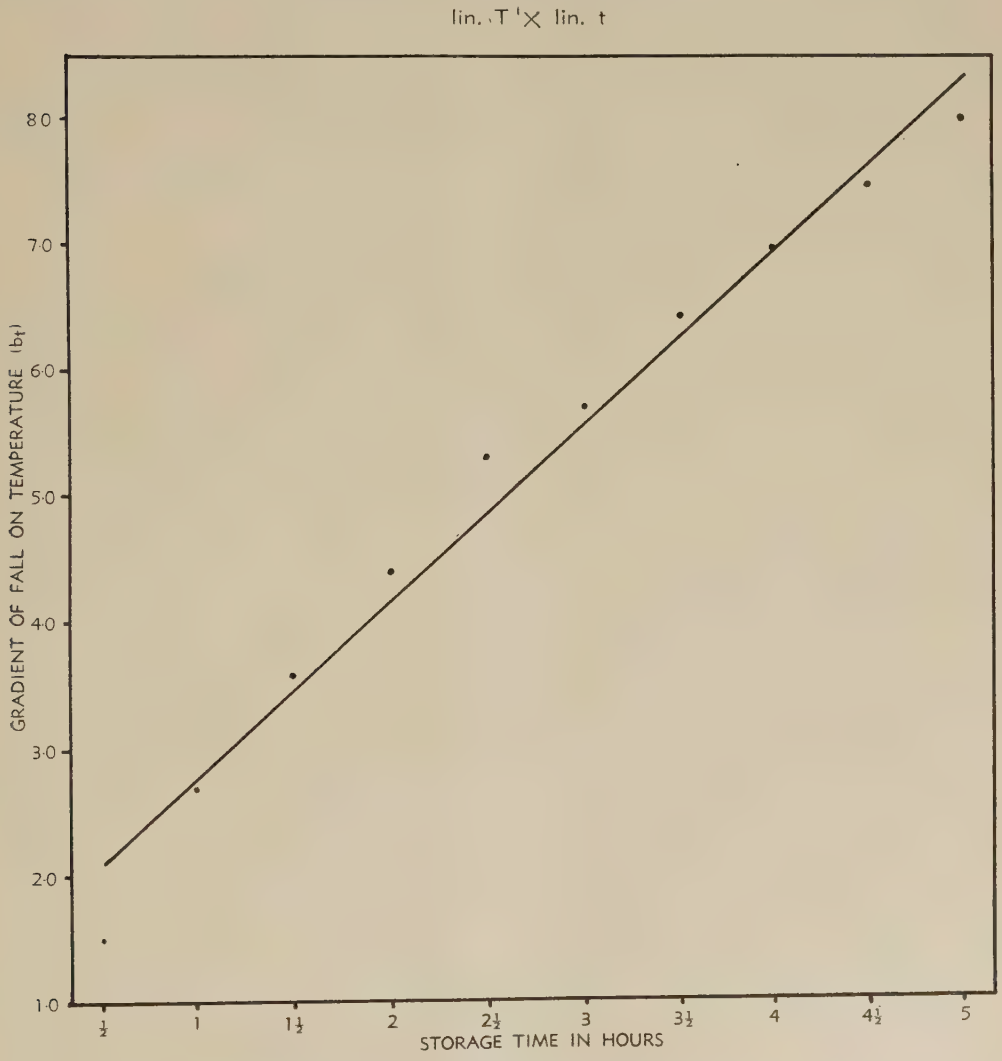


Figure 5.

Showing the effect of storage time on the gradient of fall in reduction time over the temperature range 20° C. to 35° C.

The significance of the dev. t × lin. T term in the analysis of variance indicates that the rate of change of the temperature gradient with time (Figure 5) is not strictly linear, the quadratic term showing that the regression of b_t on time changes at the rate of — 0·0406 per half-hour.

The mean values of f averaged over all storage times show a progressive increase with temperature. This same positive trend with temperature increase is shown by the gradients on time, which are shown in Figure 6. The calculated linear relation is

$$b_T - 2{\cdot}160 = 0{\cdot}694 \times \underset{\text{lin. t} \times \text{lin. T}}{\frac{(T - 27{\cdot}5)}{5}},$$

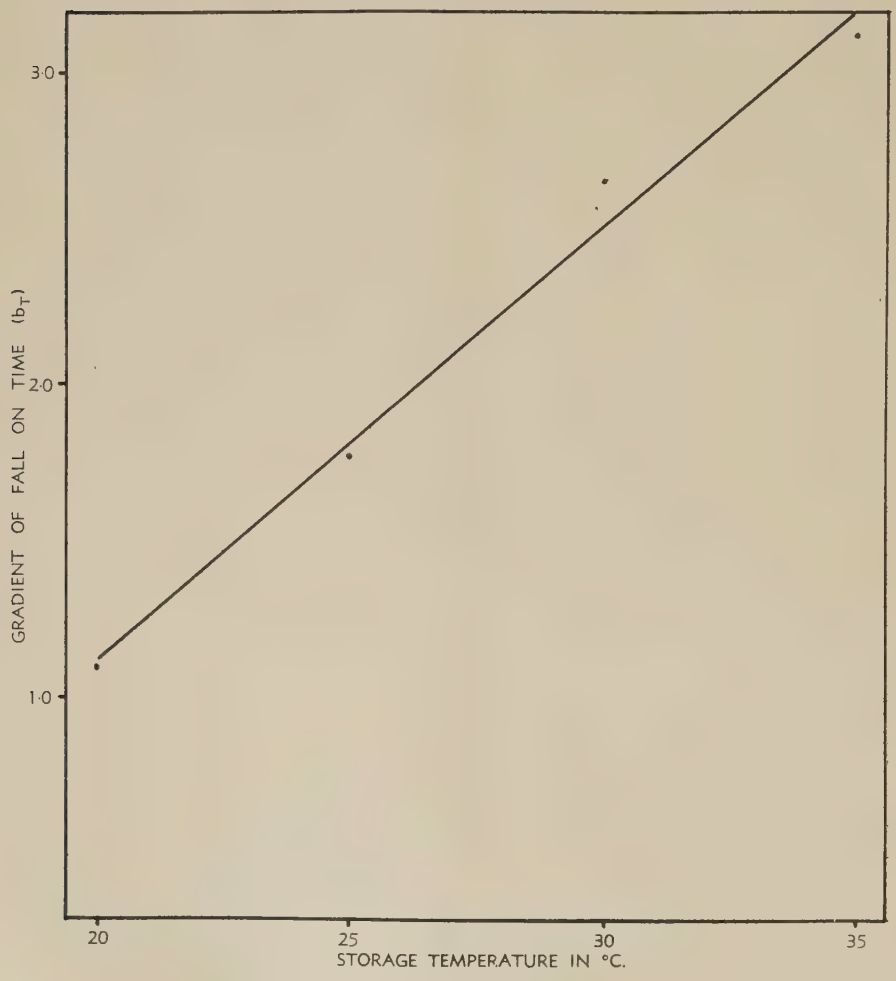


Figure 6.

Showing the effect of storage temperature on the gradient of fall in reduction time with storage time up to 5 hours.

indicating that the mean increase in the gradient of f on time is 0.694 ± 0.0597 for each 5 deg. C. change in storage temperature. Here again there appears a significant deviation from the linear, which is shown by the significance of the lin. t $\times$ dev. T term in the analysis of variance.

CORRELATION OF CONTROL VALUE AND SHADE TEMPERATURE WITH TIME AND TEMPERATURE EFFECTS.

In addition to studying the deterioration in reduction time of raw milk caused by adverse conditions of time and temperature, it was found possible to obtain from the same data some indication of the effect of the initial quality of a milk on its subsequent behaviour. The control reduction time of milk tested two hours after the completion of milking was taken as a measure of initial quality. In addition, the data were examined with a view to locating any trends which may have resulted from differences in air temperature from one day of testing to another.

Hourly mean shade temperature records commencing at 1 a.m. on the days on which the tests were conducted were obtained from the Brisbane Meteorological Observatory. Since this observatory is situated no further than 25 miles from experimental farms and there are no climatic barriers, these records were taken as indicative of temperatures prevailing on the farms. Air temperatures were recorded at several farms at the time of sampling (approximately 7 a.m.). The maximum difference between these observations and official Brisbane recordings at the same hour was 6 deg. F. and the mean difference 1 deg. F. Since air temperatures in dairy houses can be affected by a great many factors which are largely excluded by the use of a suitably constructed and properly situated shade temperature cabinet, these results do not form an accurate check. Nevertheless they serve to indicate that comparable temperature conditions prevailed at both localities.

Experimental Results.

In the analysis of the results obtained, the control value and the mean daily shade temperature were treated as independent variables and an analysis of covariance was carried out for each of the following quantities calculated for each of the 20 suppliers:—

(*a*), Mean fall in reduction time averaged over all times and temperatures;

(*b*), The regression on time averaged over all temperatures;

(*c*), The regression on temperature averaged over all times; and

(*d*), The regression on time of the regression on temperature.

The calculated values of these four variables are given in Table 5, together with the observed values of controls and shade temperatures.

In each case the fitted equation was of the form

$$y-\bar{y} = b_1 (x_1-\bar{x}_1) + b_2 (x_2-\bar{x}_2),$$

where x_1 represents the control value expressed in eighths of an hour and x_2 the mean daily shade temperature in degrees Fahrenheit.

The analysis of covariance for each of the four calculated variables is given in Table 6.

In no case is there any evidence of significant correlation of any of the four variables with shade temperature. Control values, however, show significant correlations with regressions on storage temperature and with lin. t $\times$ lin. T, but not with regression on storage time.

Table 5.

EFFECT OF CONTROL VALUE AND SHADE TEMPERATURE.

Sample No.	Total Fall in reduction time in eighths of an hour. (y_1).	Regression on Time. (y_2).	Regression on Temperature. (y_3).	lin. t x lin. T. (y_4)	Control Value in eighths of an hour. (x_1).	Shade Temperature °F. (x_2).
1	455	1,539	535	1,323	46	73·8
2	542	1,538	366	474	36	71·1
3	516	1,442	428	958	40	70·2
4	476	1,412	378	798	36	72·5
5	431	1,407	339	427	30	73·5
6	549	1,335	413	691	50	72·1
7	550	1,864	514	1,452	42	74·9
8	555	1,563	459	1,019	39	76·9
9	419	1,699	477	1,069	36	77·1
10	472	1,298	404	818	34	77·1
11	203	759	727	895	36	79·4
12	459	1,529	605	1,067	40	79·4
13	446	1,150	550	806	28	78·8
14	505	1,453	565	1,697	50	78·8
15	443	1,363	567	1,099	38	77·0
16	422	1,126	608	1,976	54	77·0
17	414	1,390	622	1,254	44	64·8
18	356	1,336	560	1,804	58	65·4
19	480	1,696	640	1,616	52	63·8
20	504	1,616	652	1,652	52	69·7

Table 6.

ANALYSIS OF COVARIANCE.

(*a*) Mean Fall in Reduction Time.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Regression	2	39·424	19·712
Remainder	17	3,038,690	198·746
Suppliers	19	3,078·114	

$b_1 = 0{\cdot}00257 \pm 0{\cdot}0062$ (not significant);
$b_2 = -0{\cdot}0441 \pm 0{\cdot}1127$ (not significant).

(*b*) Regression on Time.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Regression	2	75·595	37·798
Remainder	17	743·117	43·713
Suppliers x lin. t	19	818·712	

$b_1 = 0{\cdot}000550 \pm 0{\cdot}0114$ (not significant);
$b_2 = -0{\cdot}0219 \pm 0{\cdot}0194$ (not significant).

(*c*) Regression on Temperature.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Regression	2	267·146	133·573
Remainder	17	845·939	49·761
Suppliers x lin. T	19	1,113·085	

F for regression = 2·684, which is not significant.
$b_1 = 0{\cdot}0724 \pm 0{\cdot}0312$ (significant at 5% level);
$b_2 = 0{\cdot}0572 \pm 0{\cdot}0532$ (not significant).

(*d*) Regression on Time of Regression on Temperature.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Regression	2	394·467	197·234
Remainder	17	164·277	9·663
Suppliers x lin. t x lin. T	19	558·744	

F for regression = 20·41, which is highly significant.
$b_1 = 0{\cdot}0296 \pm 0{\cdot}00479$ (highly significant);
$b_2 = 0{\cdot}0124 \pm 0{\cdot}00816$ (not significant).

EFFECTS OF STORAGE TIME AND TEMPERATURE WITHIN THE TEMPERATURE RANGE 5 DEG. C.–15 DEG. C.

The low-temperature treatment of milk samples for methylene blue testing has been the subject of considerable investigation and discussion. Ellenberger and Moody (1930) found that milk samples iced for two hours prior to testing showed a mean reduction time 15 minutes less than samples of the same milk uniced. The effect of icing was further studied by Wilson (1935), who concluded that icing caused a lengthening of the reduction time but that the effect varied with different types of milk. Frayer (1934) found that incubating raw milk for 24 hours at 40 deg. F. prolonged the average reduction time by 5 per cent. A progressive lowering in reduction time was demonstrated by Chalmers (1938), when he held raw milk samples for 1, 7, 16 and 23 hours at 15 deg. C. A similar result was obtained by Powell, Jenkins and Thomas (1939), who observed a reduction time three and a-half hours longer with milks held overnight at 40 deg. F. than with duplicates held at 60 deg. F. Phillips and Thomas (1939) found that by holding fresh raw milk for 24 hours at three temperatures—40 deg. F., 60 deg. F. and 70 deg. F.—the reduction time of seven hours became 8·1, 5·0 and 0·9 hours for the respective temperatures.

It was considered that by the study of only four temperatures—20 deg. C., 25 deg. C., 30 deg. C. and 35 deg. C.—an incomplete picture was obtained of the response to temperature change shown by the reduction time of raw milk. Consequently, later samples of milk examined were incubated for 10 incubation periods up to five hours at 5 deg. C., 10 deg. C. and 15 deg. C. in addition to the four temperatures stated above. The experimental technique was similar to that employed in the earlier experiments. Samples were exposed to atmospheric temperature for approximately two hours between the completion of milking and the commencement of testing, and duplicate tests were again performed. Water baths operating automatically at these low temperatures were unavailable and temperature control had to be accomplished by the addition of hot or cold water whenever necessary. A laboratory refrigerator operating at 4-5 deg. C. facilitated the control of the 5 deg. C. and 10 deg. C. treatments. Care was taken that the temperature error did not exceed $\pm$ 1·0 deg. C. When laboratory air temperatures varied between 20 deg. C. and 30 deg. C. it was found necessary to inspect water bath temperatures at intervals of 10 minutes.

Experimental Results.

A summary of the results obtained over 10 periods from one half-hour to five hours at 5 deg. C., 10 deg. C. and 15 deg. C. is given in Table 7, and results of the analyses of variance in Tables 8 and 9.

Table 7.

MEANS VALUES OF f IN EIGHTHS OF AN HOUR.

Storage Temp. °C.	No. of Milks.	Storage Time in hours.										Means.	Regression Coefficients.
		½	1	1½	3	2½	3	3½	4	4½	5		
5 ..	4	−2	−2·5	−0·5	− 2	−2	−2·5	−2·5	−3	−4	−4·5	−2·55	−·288
10 ..	8	−1·5	−2·25	−2	−1·25	− 2	−1·5	−2	−1·5	−2·75	−2·6	−1·94	−·078
15 ..	8	−2·4	−1·9	−·9	−1·1	−·75	−·6	·5	−·5	− ·25	·25	−·79	·267

Table 8.

ANALYSIS OF VARIANCE.

5° C.—Data from four suppliers used.

Source of Variation.	D.F.	Sum of Squares.	Mean Square.
Suppliers	3	69·1	23·033
Times			
lin. t	1	27·348	27·348
dev. t	8	17·552	2·194
	9	44·900	4·989
Error	27	61·900	2·29
Total	39	175·900	

F for lin. t = 11·929, which is highly significant.
b = −0·288 ± 0·0834 (highly significant).

The variation between times for storage at 5 deg. C. is adequately described by the linear relation

$$f + 2{\cdot}55 = -2 \times 0{\cdot}288\,(t - 2{\cdot}75).$$

The mean fall in reduction time is $-2{\cdot}55 \pm 0{\cdot}239$ and is significantly different from zero.

Table 9.

ANALYSES OF VARIANCE (SUMMARY).

10° C. and 15° C.—Data from eight suppliers used.

Source of Variation.	D.F.	Mean Squares.	
		10° C.	15° C.
Suppliers	7	14·427	15·898
Times			
lin. t	1	4·019	47·200
dev. t	8	1·787	1·914
	9	2·035	6·946
Error	63	1·832	2·247
F for lin. t		2·194 Not significant	21·002 Highly significant

For 10 deg. C. the equation is

$$f + 1{\cdot}94 = -2 \times 0.078\ (t - 2{\cdot}75).$$

The mean value of f is $-1{\cdot}94 \pm 0{\cdot}151$ and is significantly different from zero. There is no evidence of any trend with time, the regression coefficient $-0{\cdot}78 \pm 0{\cdot}0526$ not being significantly different from zero.

For 15 deg. C. the equation is

$$f + 0{\cdot}79 = 2 \times 0{\cdot}267\ (t - 2{\cdot}75).$$

The mean fall in reduction time is $-0{\cdot}79 \pm 0{\cdot}167$ and is significantly different from zero. There is a very marked trend with time, the regression coefficient $0{\cdot}267 \pm 0{\cdot}0584$ being highly significant.

Despite the low number of replications employed—four in the case of 5 deg. C. and eight for both 10 deg. C. and 15 deg. C.—it is possible to demonstrate significant trends. The analysis of variance given in Table 8 shows that at 5 deg. C. lin. t is highly significant and is negative. In other words, there is a significant negative fall in reduction time as storage time increases. This means that at 5 deg. C. the mean reduction time of a number of milks shows a progressive increase over a 5-hour incubation period. This finding is in keeping with the observations of other workers (Chalmers, 1938; Ellenberger and Moody, 1930; Frayer, 1934; Phillips and Thomas, 1939; Powell *et al.*, 1939; Wilson, 1935). Further, this negative trend in the value of f is linear, since dev. t is not significant. The gradient of fall (b) $= -0{\cdot}288 \pm 0{\cdot}0834$ and is highly significant. The mean fall in reduction time is $-2{\cdot}55 \pm 0{\cdot}239$ and is significantly different from zero.

There is no evidence of any time trend at 10 deg. C., the regression coefficient or gradient for lin. t not being significant. It would appear from this data that the "neutral" point with respect to the effect of storage time on the reduction time lies in the vicinity of 10 deg. C. There is, as in the case of the 5 deg. C. treatment, a significant and almost spontaneous lowering of f, the mean value of this being of the order of $-1{\cdot}94 \pm 0{\cdot}151$.

A highly significant linear trend with time is found at 15 deg. C., the gradient of f being $0{\cdot}267 \pm 0{\cdot}0587$. The deviation from the linear (dev. t) is insignificant. It is to be noted that this gradient has a positive value, so that storage at 15 deg. C. results in a lowering in reduction time. Over a 5-hour period, however, there is a significant mean f value of $-0{\cdot}79 \pm 0{\cdot}167$.

The value of f averaged over all suppliers is plotted against storage time in Figure 7, in which the observed results for the four higher temperatures are also included for comparison. It will be observed that at and below 20 deg. C. a storage time of one half-hour results in a spontaneous lowering of f. This means a lengthening of the reduction time for each temperature, and is largely reflected in the mean value of f averaged over all storage periods up to five hours, and given in Table 10. This effect evidently occurs as an immediate result of the sudden change in temperature of the sample from atmospheric temperature to that of incubation, the effect being approximately equal at all three low temperatures and preceding any trends with time.

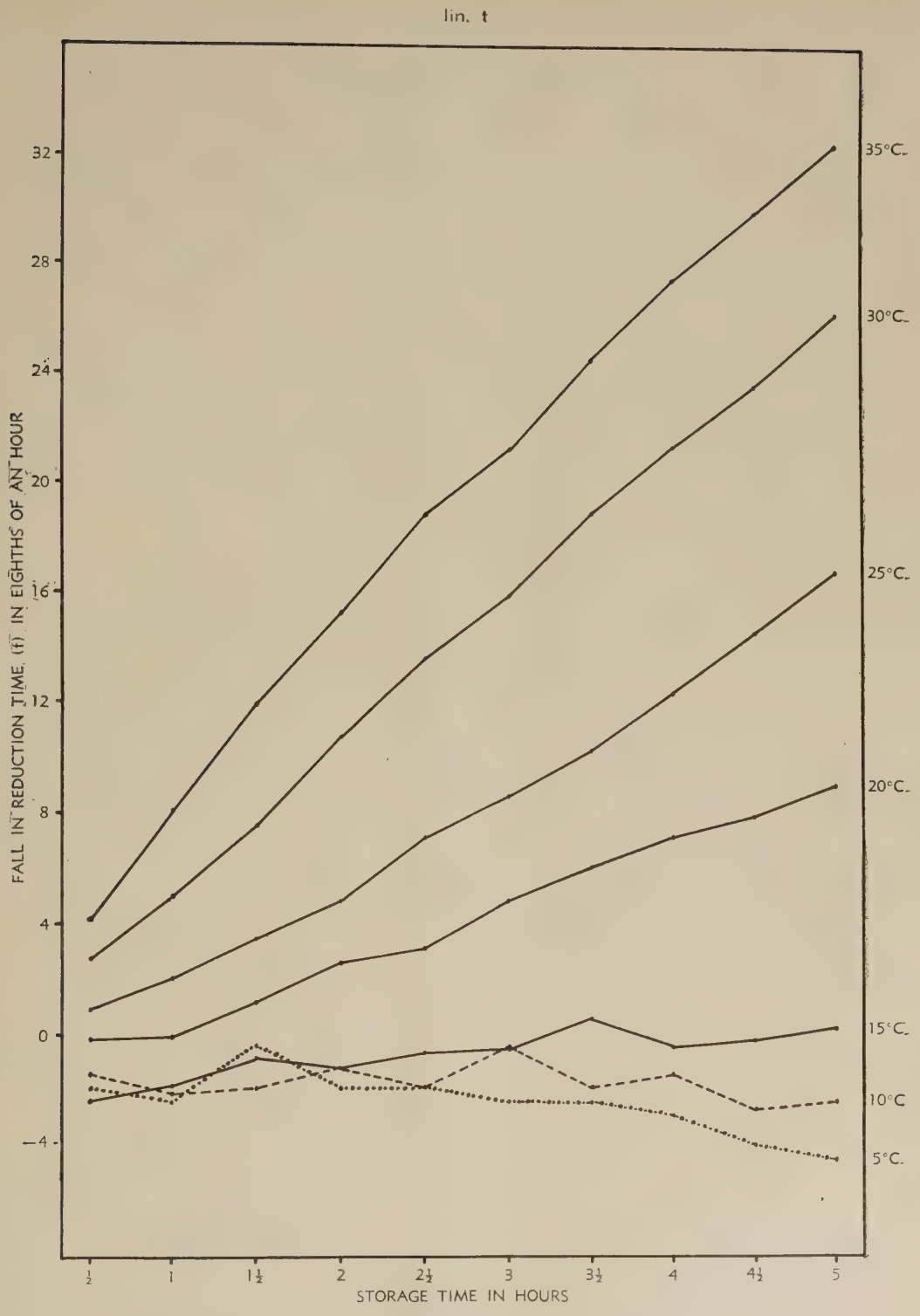


Figure 7.

Showing the effect of storage time on the fall in reduction time at seven temperatures.

Table 10.

Storage Temperature. ° C.	Mean Fall in Reduction. Time (f) over a 5-hour period.	Gradient of f in eighthsof an hour for each ½-hourly interval over a 5-hour period.
5	— 2·55 ± 0·0834	— 0·288 ± 0·239
10	— 1·94 ± 0·151	— 0·078 ± 0·0526
15	— ·79 ± 0·167	0·267 ± 0·0584
20	4·14	1·099
25	8·02 ± ·165	1·773 ± 0·162
30	14·51	2·650
35	19·32	3·119

DISCUSSION.

The effects of time and temperature on the reduction of methylene blue are interdependent. It is necessary, therefore, to consider these factors together when interpreting results. Nevertheless, the effect of the individual factor (i.e., time or temperature) can be studied most satisfactorily by keeping the other constant, and this has been done throughout the work. In this discussion the effects of the individual factors will be considered separately before discussing the interaction between the two.

Effects of Storage Time.

The reduction time of incubated samples shows a very marked response to increased storage time. At temperatures within the range 15 deg. C. to 35 deg. C. increased storage time prior to conducting the methylene blue test results in a progressive shortening of the reduction time. It has not been possible to demonstrate any trends resulting from increased storage time up to five hours at 10 deg. C., and it appears that in the vicinity of this temperature the effect of the time factor is negligible or absent. Low temperature storage at 5 deg. C. results in a progressive increase in the reduction time over a 5-hour period.

All trends resulting from increased storage time have been found to be strictly linear. Regression coefficients calculated from the observed fall in reduction time can be expressed for each storage temperature. Such coefficients are, in effect, the mean gradients of deterioration of the number of milks tested, and are given in Table 11. These results have been recalculated from Table 10 so as to be simply expressed in minutes instead of eighths of an hour.

Table 11.

Storage Temperature. ° C.	Deterioration Gradient (decrease in the reduction time for every ½-hour increase in storage time up to 5 hours). Minutes.
5	— 2·2
10	0
15	2·0
20	8·2
25	13·3
30	19·9
35	23·4

It will be observed that the time deterioration gradient is negative at 5 deg. C. and becomes positive at 15 deg. C. Regardless of the fact that these results are a true expression of the low temperature time gradients, they are not adequate to express fully the observed results, since temperatures of 20 deg. C. and lower cause an increase in reduction time even after a storage period as short as 30 minutes. Consequently any time trends must occur subsequent to this phenomenon and must commence with a milk possessing a reduction time longer than the control sample. Thus at 15 deg. C., five hours' storage results in a reduction time approximately equal to the initial reduction time prior to storage.

It is obvious from these results that any increase in the storage period or any delay in transport of raw milk is to be avoided when the milk temperature rises above 15 deg. C. (59 deg. F.).

Following this experimental work further information was obtained with incubation periods extending to 10 hours. The data, which are as yet unpublished, indicate that the same effects and trends can be expected over an incubation period of 10 hours as were obtained over five hours.

Effects of Storage Temperature.

The storage of raw milk at temperatures between 20 deg. C. and 35 deg. C. results in a marked shortening of the methylene blue reduction time for all storage periods up to five hours. As the temperature of storage increases the reduction time decreases in a manner which does not strictly obey the linear law. Both the quadratic and the cubic terms are significant. Figure 4 shows the curves obtained by varying the incubation temperature from 20 deg. C. to 35 deg. C. for all storage times. It will be noticed that the greatest effect on the reduction time occurs between the temperatures 25 deg. C. and 30 deg. C. All curves show a comparative decrease in gradient between 20 deg. C. and 25 deg. C. and between 30 deg. C. and 35 deg. C. It is presumed that the temperature range of greatest gradient coincides with the optimum growth temperature for most of the bacterial strains making up the floras of the various milks. Despite these deviations the greater portion of the differences between means at each temperature is for general purposes linear.

A very marked and very sudden increase in the reduction time was observed at temperatures of 5 deg. C., 10 deg. C. and 15 deg. C. This increase was noticeable after half-an-hour's storage, and is clearly shown in Figure 7. The same figure also shows that at 20 deg. C. storage for the same period caused a similar but much smaller increase to be followed by the marked linear trend of a falling reduction time. All four temperatures—5 deg. C., 10 deg. C., 15 deg. C. and 20 deg. C.—were below atmospheric temperature and were lower than the temperatures of all samples prior to commencing incubations (i.e., 23 deg. C.-29 deg. C.). It would appear from this evidence that when the temperature of raw milk samples is suddenly lowered to 20 deg. C. or lower a storage period of one half-hour at these temperatures results in a lengthing of the reduction time which is independent of the amount of temperature change. The reason for this

is not clear and was not investigated. It is suggested that two factors may be involved: (*a*), the induction of a lag growth phase for at least some of the organisms making up the flora, and (*b*), the increased capacity of milk at lower temperatures for taking up oxygen. The phenomenon is of practical significance in the rapid cooling of milk on the farm.

A storage temperature of 15 deg. C. causes an initial lengthening in reduction time followed by a progressive shortening in reduction time as the storage time increases over a 5-hour period. Storage at 10 deg. C. produces a similar early lengthening in reduction time, after which there is no significant change. At 5 deg. C. the initial lengthening increases in a significant linear manner over the same storage period. These points are illustrated in Figure 7. The results obtained are comparable with those reported by Phillips and Thomas (1939) and mentioned on page 148.

Interaction of Time and Temperature.

All results indicate a high degree of interaction between time and temperature. Salient features shown by the data are that in general the effect of time increases with temperature rise; and, conversely, the effect of temperature increases with increase of time. While this finding is to be expected, one important exception occurs at 10 deg. C. At this temperature prolongation of storage up to five hours, and probably also to 10 hours, has no effect on the reduction time after the initial increases resulting from the sudden change in incubation temperature.

The mean fall in reduction time averaged over all temperatures shows a progressive increase with increased storage time, and the mean fall in reduction time averaged over all storage times increases progressively as the storage temperature increases.

At each storage temperature the curve of the fall in reduction time is linear, but it becomes progressively steeper as the storage temperature rises. This rate of gradient change is shown graphically in Figure 6. It is not strictly linear, but is nearly so.

In the same way the gradient of the fall in reduction time with temperature increase shows a steep rise as the storage time increases (Figure 5). Again the linear fit is not completely adequate, since a further examination of the results shows that this temperature gradient becomes less steep as the storage time increases, changing at the rate of — 0·3 minute per half-hour storage time.

Relationship Between Control Value and Rate of Change in Quality.

It has been found that the initial quality of a raw milk plays some part in determining its behaviour following storage at various temperatures and times. In fact, a definite correlation has been obtained between the control reduction time and the effect of storage temperature. This correlation shows

that good quality milks deteriorate more rapidly in response to increased storage temperature than do low quality milks. A correlation has also been found between the control value and the rate of change of the temperature deterioration gradient with increased storage time. Thus good quality milks—i.e., milks giving long methylene blue reduction times—in addition to showing a more rapid falling off in reduction time with increasing storage temperature show a more rapid rate of such falling off with increasing storage time.

Any explanation which can be offered in respect to these observations can be only speculative, but it seems probable that good quality milks by virtue of their low bacterial populations allow greater scope for bacterial development than do those of low quality. The accumulated waste products of metabolism, and possibly the antagonism between individual members of the milk flora, would tend to retard bacterial development in those milks carrying a heavy bacterial population. Since bacterial activity is the main factor governing the rate of reduction of methylene blue, this rate may be slowed up as a consequence.

Regardless of the trends observed with milks of varying quality, it is true that, within the scope of effective testing by means of methylene blue, good quality milks possess a longer reduction time following storage than do low quality milks.

Effects of Other Factors.

The data obtained by experiment were also examined for trends resulting from shade temperatures on the days of testing, but without result. Similarly no difference could be observed between hand- and machine-milking and between farm-cooled and uncooled milk.

Bactericidal Property of Fresh Milk.

This experimental work provides no evidence of any bactericidal property in fresh milk. Any such property was without effect on the methylene blue reduction time of milk examined two hours after the completion of milking. It appears, therefore, that any bactericidal action possessed by fresh milk can be ignored in milk quality control work, at least in southern Queensland.

REFERENCES.

AMERICAN PUBLIC HEALTH ASSOCIATION. 1941. Standard methods for the examination of dairy products. 8th Edition.

BARKWORTH, H. 1944. Advisory Dairy Bacteriologists—Review of papers presented from 1925-1943. Dairy Industr. IX.: 171-180.

CHALMERS, C. H. 1938. The methylene blue reduction test and the keeping quality of milk. J. Dairy Res. 9: 351-355.

ELLENBERGER, H. B., and MOODY, R. I. 1930. Preparing samples of milk for the methylene blue reduction test. Vt. Agric. Expt. Sta. Bull. 312.

FRAYER, J. M. 1934. Light and temperature as factors in the methylene blue reduction test. Vt. Agric. Expt. Sta. Bull. 374.

Hoy, W. A., and Braz, M. 1938. The methylene blue reduction test in relation to the age and storage temperature of milk. (Abstracts) Proc. Soc. Agric. Bact. 21.

Newton, W. 1942. Links in milk improvement. Dairy Industr. VII.: 203-205.

Nichols, A. A., and Edwards, S. J. 1936. The comparative values of the plate count and the modified methylene blue reduction test as routine methods for grading milk. J. Dairy Res. 7: 258-270.

Phillips, R., and Thomas, S. B. 1939. Milk cooling on the farm. Welsh J. Agric. XV.: 150-163.

Powell, H. M., Jenkins, E., and Thomas, S. B. 1939. Methylene blue reduction by duplicate samples of raw morning's milk held overnight. Welsh J. Agric. XV.: 164-168.

Procter, F. 1943 a. A study of commercial milk in wartime. Dairy Industr. VIII.: 211-214.
————. 1943 b. Milk distribution. Dairy Industr. VIII.: 272-276.

Wilson, G. S. 1935. The bacteriological grading of milk. Spec. Rep. Ser. Med. Res. Coun., London, No. 206.

A. H. Tucker, Government Printer, Brisbane.